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THE OCEAN SCIENCE PROGRAM
OF THE U.S. NAVY

*Accomplishments
and
Prospects*

JUNE 1967



OFFICE OF THE
OCEANOGRAPHER OF THE NAVY
Alexandria, Virginia

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If, instead of sending the observations of seamen to able mathematicians on land, the land would send able mathematicians to sea, it would signify much more to the improvement of navigation and to the safety of men's lives and estates on that element.

Sir Isaac Newton, 1692

Foreword

Science in this age of modern technology is still a mixture of knowledge, understanding, and curiosity used to pursue further knowledge and understanding of our natural world. The motivation of the Navy to pursue an active program in the ocean sciences is more than just curiosity; we must have the knowledge and understanding to use most effectively that three-quarters of the world covered by the oceans and seas. As a corollary, we must also deny its effective military use to potential adversaries. The scope and content of the Navy Ocean Science Program is predicated on this mandatory requirement.

This report is a summary of the Navy Ocean Science Program—its purpose, its history, its scope, and its prospects for the future. With the welcomed increasing interest in the marine sciences shown by the Congress and Executive Branch of the Federal Government and by the public, we hope that this report will serve to provide to these groups an insight into a program of which the Navy is particularly proud. This report only summarizes; the full results from the efforts described are freely published in the scientific and technical journals, except in those few instances where limited by national security requirements. We expect to continue to contribute to the needs of the nation in this manner and work to ensure that our country maintains its leadership in the effective use of the sea.

A handwritten signature in black ink, reading "A. D. Waters, Jr." The signature is written in a cursive, flowing style with a large, prominent "A" and "W".



Rear Admiral O. D. Waters, Jr., USN
Oceanographer of the Navy

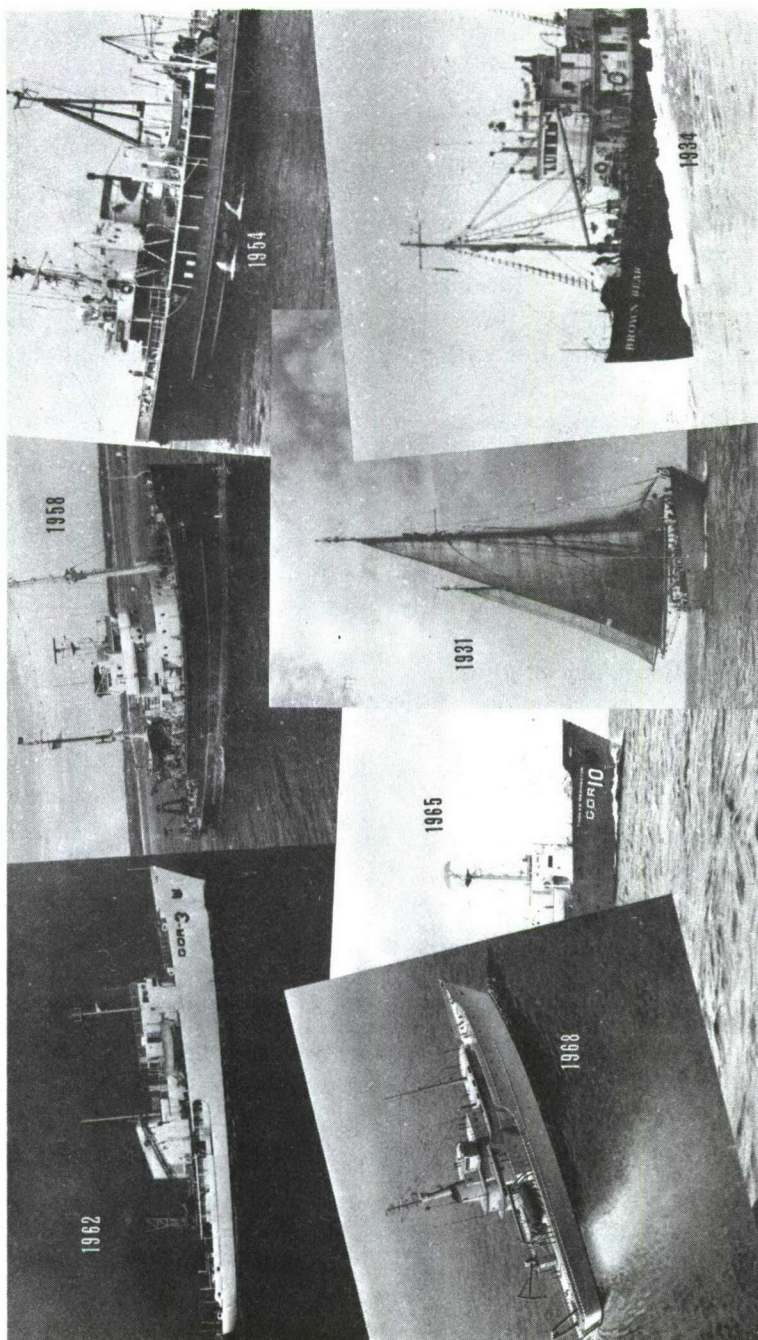
Acknowledgment

The Navy wishes to extend a "well done" to the many distinguished scientists and engineers from within Navy laboratories, the academic community, and industry, without whose scientific enthusiasm and interest the Navy Ocean Science Program described in this report would not exist. Many of these individuals and their organizations also provided photographs and illustrations for incorporation into the report. This assistance is gratefully acknowledged.

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Evolution of research vessels in the Navy Ocean Science Program

The Ocean Science Program of the U.S. Navy

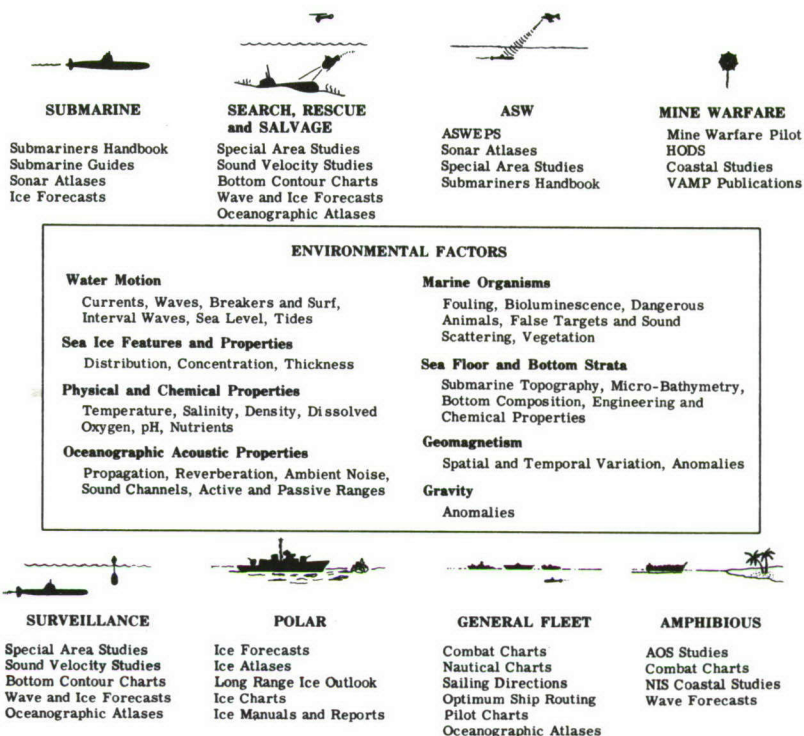
Accomplishments and Prospects

INTRODUCTION

The Navy operates above, at, and below the surface of the sea, and must build and maintain facilities on its shores and on its floor. Every phase of the sea—its motion, its chemistry, its physical properties, its life forms, its boundaries, and its energy content—vitally affect the operation of ships, weapons, and specialized equipment of the Navy. Very simply, the ability of the Navy to perform its primary missions is dependent on a comprehensive knowledge of all these facets of the oceans, and as systems become more sophisticated, this dependence will be even more apparent. The Navy, in recognition of this need, has actively supported research in all phases of marine science and technology. The needs, traditions, and natural field of operations of the Navy, as well as its resources, provide both the motivation and opportunity to pursue an aggressive oceanic research and development program.

In order to explore the oceans and lay the basis for exploiting them to meet naval needs, the Navy has developed a program—the Naval Oceanographic Program—which encompasses ocean science, technology and engineering, and operations. The scope of this quarter-of-a-billion-dollars-a-year program represents more than half of the total marine-science activities of the Federal Government. The ocean-science portion of this Navy program accounts for approximately one-fifth of the total Navy

THE NAVY OCEAN SCIENCE PROGRAM



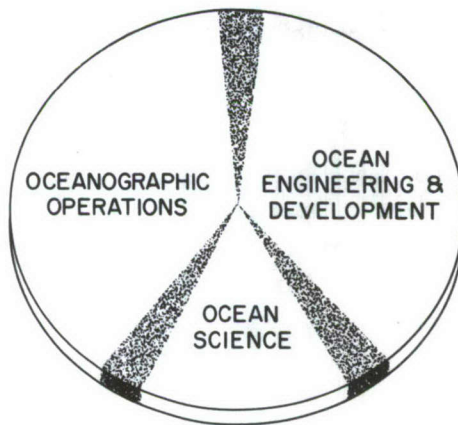
Environmental factors related to oceanography and
associated with Navy operational needs

effort. It is to this aspect of the Naval Oceanographic Program — the Navy Ocean Science Program — that this report is addressed.

OBJECTIVES OF THE OCEAN-SCIENCE PROGRAM

The Naval Oceanographic Program encompasses that body of science, technology, engineering, operations, and the personnel and facilities associated with each, which is essential primarily to explore and to lay the basis for exploitation of the ocean and its boundaries for Naval applications to enhance the security and support other national objectives.* The Navy's needs are not only broad in scientific scope but they are also worldwide in range, as

*OpNav Instruction 5450.165, August 26, 1966.



Navy Oceanographic Program, Fiscal Year 1967,
Total, \$227 million

evidenced by the Project Deep-Freeze task force activities in Antarctic waters and the contrasting environmental conditions that are encountered by task forces located in tropical waters off Southeast Asia.

The contribution of the ocean-science portion of the overall Naval Oceanographic Program to meet these Navy needs is specifically intended to advance our understanding of the nature of the world oceans and their boundaries. This program includes the study of their physical, chemical, biological, and geological characteristics so as to achieve an ability to describe, utilize, forecast, and, if possible, modify them. These studies span scientific and associated technological efforts which range from research undertaken to obtain a fundamental understanding of oceanic phenomena, through investigations of specific environmental conditions which affect equipment and systems, to tests of the scientific feasibility of new systems concepts.

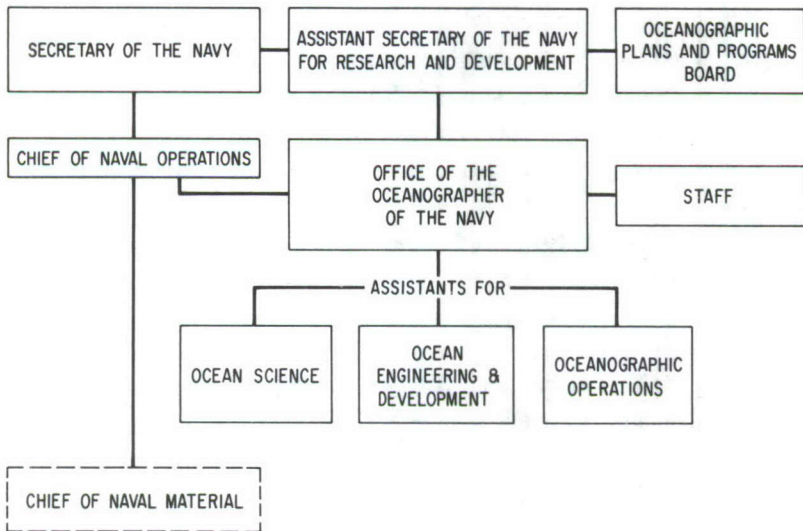
The Navy Ocean Science Program has a major impact on the Navy and national programs in many ways, and at many stages in the progression from ideas to capability. This impact is aptly demonstrated by the example of a study undertaken in 1956, for which a group was convened to review and make recommendations on undersea warfare. From this group, over half of which were from the Navy Ocean Science Program, came the

basic concepts of several of today's major weapons systems. Members of this group included many of the same scientists who in offices, laboratories, or ships cooperated to test the scientific feasibility of these new concepts. Some of them even continued to assist as scientific feasibility changed to engineering development.

In pursuing this primary objective of enhancing our national security, it has been recognized that national security must be interpreted in its broadest sense—economic, political, social—since in a world without educational and economic well-being, or in a hungry world, there is no security. In developing the necessary ocean-science program to meet its objectives, the Navy has thus assumed a broader responsibility by undertaking to serve other national interests in areas where the Navy's capabilities and the national needs coincide. The Navy Ocean Science Program has since its inception actively sought to make the results of its endeavors available to all who require them and whenever possible to work on mutual problems with similarly interested agencies and groups.

ORGANIZATION AND MANAGEMENT

The management of the Navy Ocean Science Program is under the direction of the Assistant Oceanographer of the Navy for Ocean Science, whose primary duty is Chief of Naval Research. A new management structure for the Navy's overall oceanography program was recently established by instructions from the Secretary of the Navy and the Chief of Naval Operations. Under this structure, the Oceanographer of the Navy has been given the responsibility for the entire oceanography program of the Navy. He reports directly to the Chief of Naval Operations for operational matters and receives policy guidance from the Assistant Secretary of the Navy (R&D). The Oceanographer of the Navy is assisted in the management of the Navy's program by the Chief of Naval Research in his collateral assignment as Assistant Oceanographer for Ocean Science and by the Deputy



Navy Oceanographic Program management structure

Chief of Naval Material (Development) as the Assistant Oceanographer for Engineering and Development. A third assistant, the Assistant Oceanographer for Operations, is to be named.

The instruction assigning the tasks and functions to the Oceanographer of the Navy define Ocean Science as "That effort in research; development; and technical guidance in support of operations, to advance the knowledge of the physical/chemical/biological/geological nature of the world's oceans and their boundaries (surface and bottom)."* Following this instruction, the Navy Ocean Science Program presented in this report has been separately identified among continuing individual research-and-development programs of the Office of Naval Research, the Naval Material Command, the Naval Oceanographic Office, the Bureau of Medicine, and the Naval Weather Service. The nature of the work and the type of questions or problems addressed have provided the basis for identification of the Navy

*OpNav Instruction 5450.165.

Ocean Science Program. If projects were largely scientific, or clearly in support of scientific inquiry, then they were made part of the Navy Ocean Science Program. Much of this program is carried out as an integral part of other specific mission-oriented activities, such as undersea warfare and amphibious warfare. This coupling is necessary to ensure direct and adequate input of environmental understanding into systems, equipments, and operations vital to the national security. The interactions among scientists and engineers in research programs, those in systems development, and naval officers and operations analysts must be a continual process for each to be productively aware of the capabilities, knowledge, and needs of the others. The scientist must be somewhat aware of operational requirements if the environmental knowledge he develops is to be useful to the naval line officer, just as the naval officer or the operations analyst must know the true extent of environmental influence. It is extremely difficult to maintain adequate exchange among these groups even within the same organization. It is doubtful that a non-naval environmental research group could achieve a fruitful involvement in Navy problems, except for short periods.

The Assistant Oceanographer for Ocean Science has under his cognizance a spectrum of groups and types of support which, when combined, constitute a well-balanced ocean-science program for the Navy. The Office of Naval Research, under its contract research program, has long fostered the support and development of centers of excellence in the area of ocean science. Consequently, the ONR program is oriented toward institutional and university contracts, for programs that have been developed jointly by that office and the laboratory directors and staffs. These contracts provide a broadly based program to support the variety of Navy needs. In addition, ONR has long maintained a policy of continuity of support; that is, it has attempted to provide stability in a field of science where capital and operating costs for research are higher than average. To further focus the Navy Ocean Science Program under the Chief of Naval Research, two actions have recently been taken. Internally, within ONR several programs were combined in

late 1965 into the Ocean Science and Technology Group, and early in 1966 a new program was begun, with the formation of the Ocean Sciences and Engineering Division of the Naval Research Laboratory. These actions were undertaken to consolidate and strengthen the Navy research ocean-science efforts. Concurrently, the Naval Oceanographic Office identified a research and development group whose activities were largely devoted to ocean science. These three groups were moved to the same building at the Naval Research Laboratory. This collocation has been regarded as a potential Washington headquarters for the Ocean Science Program of the Navy. During the past ten months, these three groups, a number of private contractors, and several groups from laboratories from the Naval Material Command have cooperated on a number of specific projects in science, engineering, development, and operations analysis. In this work, the headquarters, or center, has served as a useful focal point for these activities. With this experience as a guide, a recent decision has been made to formalize this center as the Maury Center for Ocean Science of the Navy.

The ocean-science programs sponsored by the commands under the Chief of Naval Material have tended to concentrate on the development of an in-house capability for research in ocean science at each of the Navy laboratories and the university research centers, such as the Ordnance Research Laboratory at Pennsylvania State University and the Applied Physics Laboratory at the University of Washington. Equipment and systems development programs thus have close contact with programs of ocean science. The Navy Material programs rely mainly upon ONR programs at the universities and private institutions and upon Navy laboratory research groups to provide the basic research from which the major applied efforts of Navy laboratories grow. Program review and documentation exchange exist to help integrate these programs. To insure integration at the laboratory levels, there is considerable direct contact among the universities and private laboratories and the Navy, particularly among the working scientists and engineers. As examples, in the San

Diego area, the Scripps Institution of Oceanography and the Navy Electronics Laboratory work closely together and have some facilities collocated, while on the Gulf Coast the Mine Defense Laboratory and Texas A&M University interact. In the northeast, the Navy Underwater Sound Laboratory has a long history of cooperation with the Woods Hole Oceanographic Institution, with the University of Rhode Island, and with the Lamont Geological Observatory and Hudson Laboratories of Columbia University. Therefore, when treated as a whole, the Navy Ocean Science Program represents a balance of research and development activities to meet the many Navy needs for understanding of the ocean environment which are essential "to explore and to lay the basis for exploitation of the ocean and its boundaries for Naval applications to enhance security and support other national objectives."*

THE HISTORY OF OCEAN SCIENCE IN THE NAVY

Growth of the Navy's Program

The Navy's interest and leadership in developing systematic knowledge of the oceans and applying this knowledge dates back to the period of Lieutenants Matthew Fontaine Maury and Charles Wilkes, more than a century and a quarter ago. The vigorous quest for knowledge of the oceans undertaken by these pioneers in the field of modern oceanography unfortunately was not continued by the Navy or the nation as a whole through the intervening years. It was not until World War II that the Navy again undertook an aggressive scientific assault on the oceans. With the immediate needs for knowledge about the ocean environment that developed during World War II, particularly to support allied undersea warfare operations and amphibious assaults, the Navy at that time turned to the scientific community for assistance. The small cadre of scientists at the then existing oceanographic institutions constituted most

*OpNav Instruction 5450.165.

of the nation's competence, and they joined forces with the Navy to meet these wartime needs.

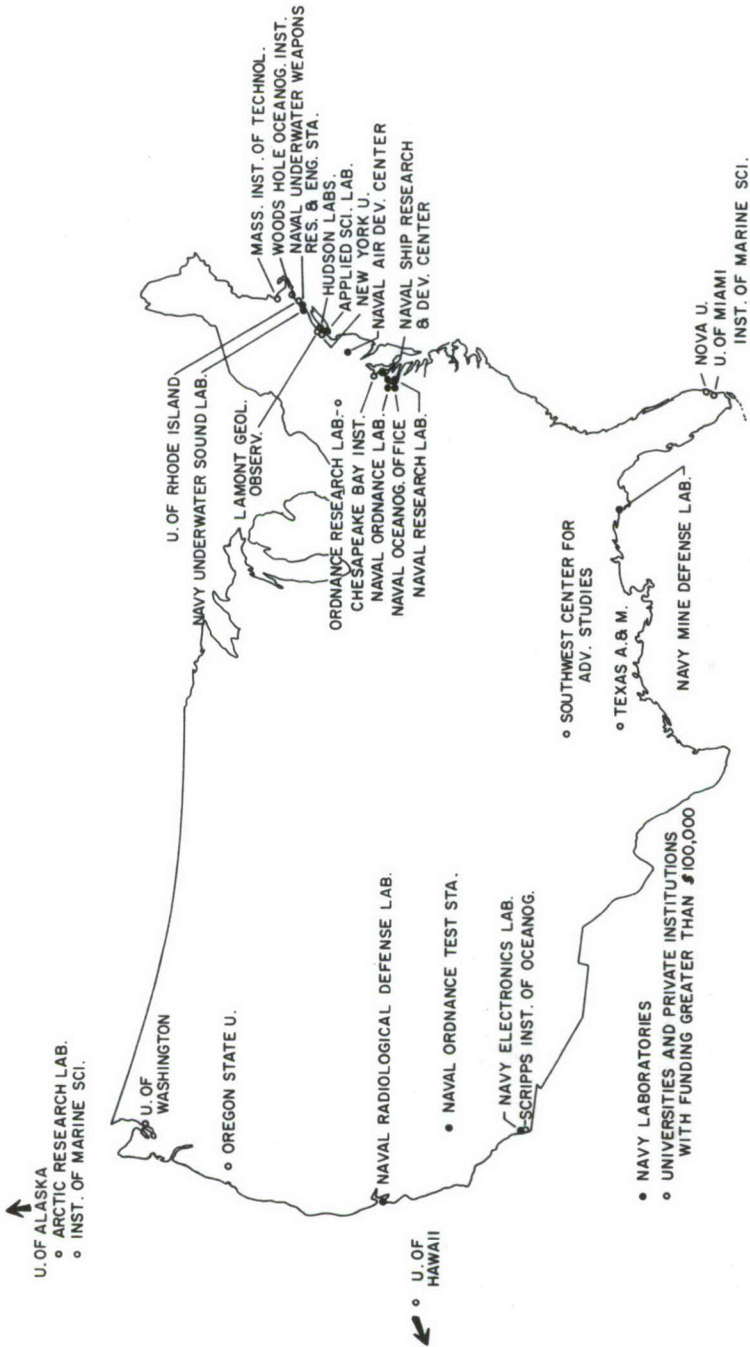
Based upon the experience gained during World War II, the Navy realized the necessity to develop a strong ocean-science program in order to obtain the understanding and knowledge needed to meet the many Naval requirements resulting from the advanced technology of World War II and later periods. Consequently, the close working relationships developed during the war between the Navy and the major oceanographic institutions were continued and encouraged to grow. Research programs by new academic groups were initiated, graduate-student training was encouraged to meet critical manpower shortages, new laboratory and ship facilities were provided, and new avenues for research and methods of attack were encouraged. These programs were started mostly through the combined efforts of the former Bureau of Ships and ONR, who provided the first significant postwar increase of support, in 1950.

Ocean-science programs also were initiated within the Navy in-house laboratory structure. The intent of these programs was to bridge the gap between the basic research conducted by the academic community and projects associated with the development of specific equipments. New research groups were formed at the Navy laboratories and the Naval Oceanographic Office to accomplish this. Physical facilities were provided; many of them, such as the sea-ice pool at the Navy Electronics Laboratory, represent a unique national capability. Research ships as well as submersibles, towers, and other platforms also were obtained. In many cases these, too, represent unique research opportunities.

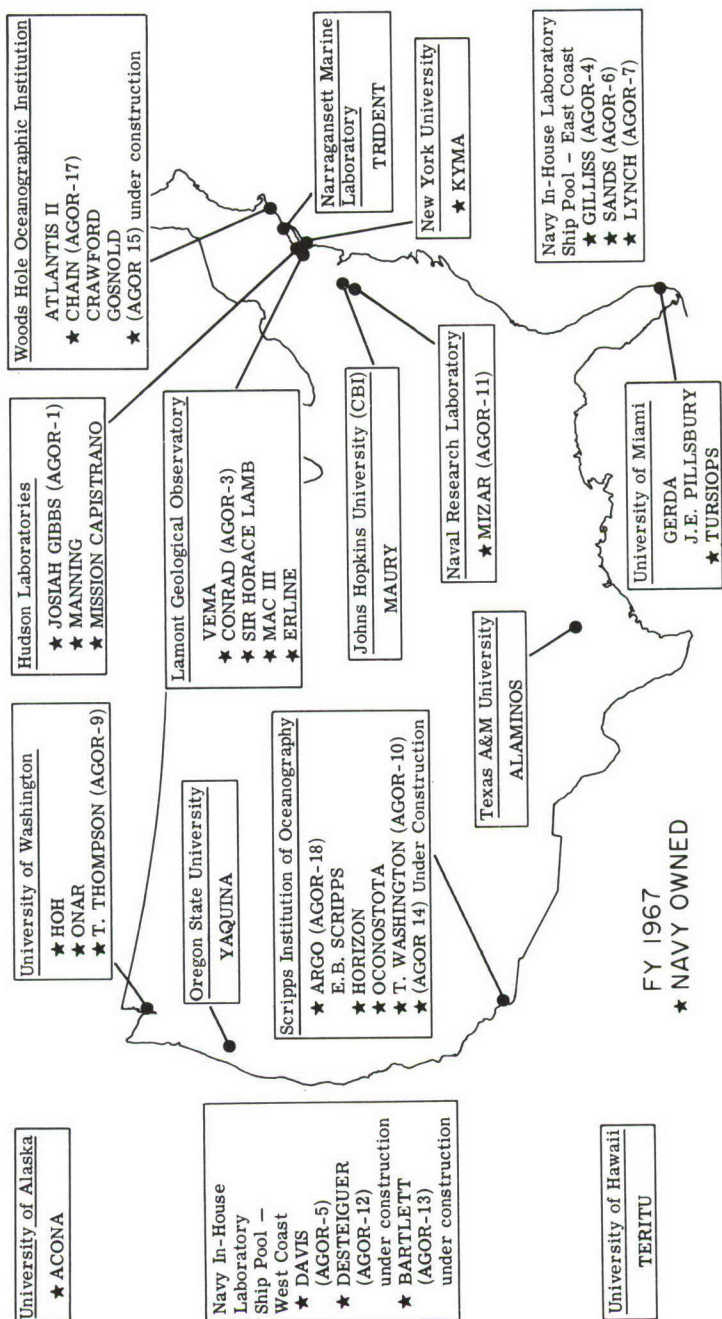
Through research conducted at these Navy laboratories and at the universities and private institutions, the Navy now supports a program of unprecedented scientific scope and capability. Individual investigations range from the study of the geological structure of the ocean depths to exchange processes across the sea surface, and from the movement of micro-organisms to the dynamics of major ocean-current systems. These investigations

extend from the arctic basin to the equator. The magnitude of this effort is reflected in the levels of support provided to groups intimately involved. The cost of supporting the research of an investigator full-time in ocean science today is annually about \$60,000 to \$75,000, including the support required for research ships. The Navy laboratory ocean-science efforts, now centered at 13 separate activities, range from single-man-year efforts to programs in excess of \$1,000,000 a year. These programs are complemented by research being conducted by the academic community. At present 18 academic and private institutions are engaged in ocean-science research programs sponsored by the Navy at levels in excess of \$100,000 a year. At six of these organizations the Navy support exceeds \$500,000 a year, and at another six, \$1,000,000. As large as these programs and their scientific scope may be, the Navy Ocean Science Program also has enjoyed long-term associations, on much smaller scale efforts, with many individual investigators in the academic community. Industry, too, plays a vital role in the Navy Ocean Science Program, mainly through the development of large equipments and systems necessary to conduct research and, through subcontracting, to carry out individual projects for the Navy laboratories, universities, and private institutions. In total, the Navy's program involves the talents of Navy scientists, the academic community, and industry.

The fleet available to the Navy Ocean Science Program to provide research platforms from which to conduct at-sea investigations now numbers some 34 ships, ranging in size from converted 65-foot T-boats for coastal investigations to the 10,000-ton USNS MISSION CAPISTRANO, used for studies of underwater acoustics in the North Atlantic Ocean. This fleet has evolved from pre-World War II ships such as the auxiliary ketch ATLANTIS, formerly of the Woods Hole Oceanographic Institution, through a series of converted hull configurations to two classes of new construction, the AGOR-3 and AGOR-14 classes. Of the 34 ships now in the program, the Navy owns 23. Of these, 16 are operated by universities and private institutions, where they are used for the Navy programs and also for other federally sponsored efforts.



Navy Ocean Science Program—locations of major Navy laboratories, and Navy-supported universities and private institutions



Oceanographic research vessels employed in the Navy Ocean Science Program

The Navy laboratories have acquired four AGOR-3 class research ships since 1963, and it is planned to increase this capability materially by replacing the leftover World War II militarily configured ships now in use. The availability of the number of ocean-going ships by Navy laboratories, universities, and private institutions provides the Navy and the country the capability to conduct ocean-science research in all areas of the world oceans.

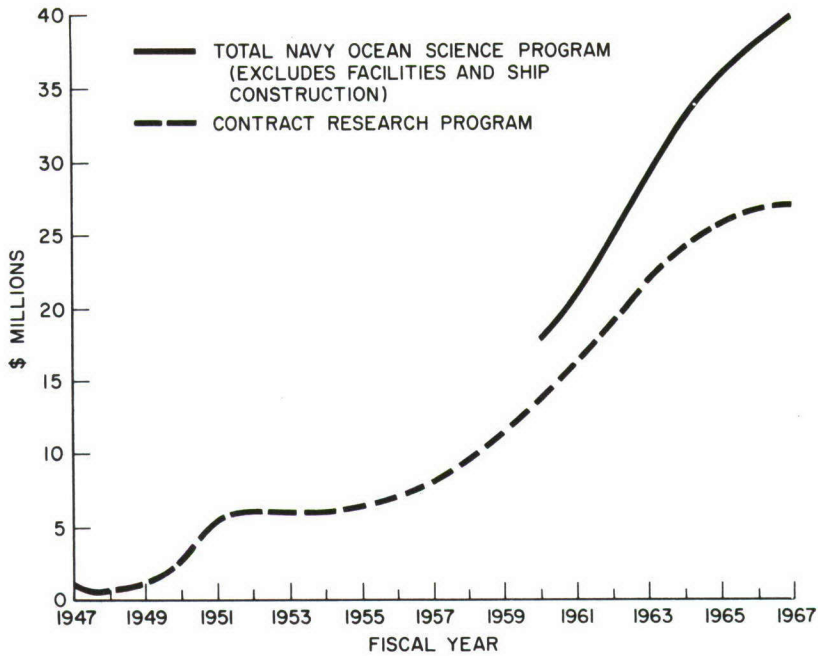
The research fleet is also supplemented by a variety of other types of platforms that have been developed to meet the needs of the Navy Ocean Science Program. They include the following:

1. A capability to establish scientific camps on drifting ice in the arctic basin
2. Tower structures suitable to maintain scientific teams and equipment for extended periods of time (such as Argus Island, located in the North Atlantic Ocean 30 miles southwest of Bermuda)
3. Aircraft that range in size from single-engine to four-engine long-range craft
4. Buoy systems to collect oceanographic data continuously for periods extending to a year
5. Underwater research vehicles able to take man to any depth in the oceans.

As a result of the Navy efforts to develop these facilities, together with the manpower and program of scientific and technological inquiry, a national resource now exists so that the Navy and the nation can undertake the exploration and exploitation of the oceans.

Participation in National Ocean Science

In developing its own ocean-science program, the Navy has had a significant influence on the national oceanographic effort, particularly in the past decade. The initial upsurge in oceanography in the post-World War II period began in 1950. The most significant expansion, however, has taken place since the late 1950's. One contributing factor in this upsurge was the



Funding history of Navy Ocean Science Program

U.S. participation in the International Geophysical Year (1957-1958), of which the oceanographic program was a significant part. Another factor was the recognized need by the Navy for greater knowledge of the ocean with the advent of the nuclear submarine and the attendant undersea warfare problems. The search for the THRESHER and, more recently, the recovery of the unarmed nuclear weapon off Spain have further emphasized the need for greater understanding of the ocean environment to meet the operational needs of the Navy.

The first Navy long-range planning document for oceanography, the Ten Year Program in Oceanography (TENOC), was endorsed by the Chief of Naval Operations on Jan. 1, 1959. By this action, it became firm Navy policy to promote and support a strong oceanography program. Almost concurrently with the internal TENOC document, the National Academy of

Sciences Committee on Oceanography (NASCO) published its far-reaching report "Oceanography 1960 to 1970" in February 1959. This study was requested by the Chief of Naval Research and the Bureau of Commercial Fisheries.

With the awakening federal interest in oceanography that followed the issuance of this report, the Navy assumed the role of national leadership. Dr. James Wakelin, then the Assistant Secretary of the Navy for Research and Development, became the first Chairman of the Interagency Committee on Oceanography in 1960 and guided it through the early period of developing a coordinated Federal Oceanography Program. Within this program, the Navy, working closely with the National Science Foundation, assumed major federal responsibility for developing an academic and institutional capability in ocean-science research and strengthening the government program through increased efforts of the in-house Navy laboratories. The Navy was largely responsible for the establishment of the ocean-science programs at the Johns Hopkins University, Texas A&M University, Oregon State University, and the Massachusetts Institute of Technology, as well as for the expanded efforts at the University of Rhode Island and the University of Miami. In addition to establishing new programs, the Navy also assisted appreciably in building up the capabilities of Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, Lamont Geological Observatory and Hudson Laboratories of Columbia University, New York University, and the University of Washington.

Besides providing the financial support for research and essential operating costs, the Navy has assisted these laboratories by providing ships through new construction or conversion. At present, this fleet, operated by private laboratories and jointly funded by federal agencies, receives about 50 percent of its support from the Navy. The balance of ship support required in the program is, of course, financed entirely from naval sources.

Within the framework of the Interagency Committee on Oceanography, the Navy has worked cooperatively on problems of mutual interest with other federal agencies sponsoring ocean-

ographic programs. The Navy, recognizing that much ocean-science research is exceedingly costly, particularly when ship support is considered, has jointly supported efforts of value to its program. The present EASTROPAC investigation, studying the waters of the eastern tropical Pacific, has been developed jointly with the Bureau of Commercial Fisheries and other agencies. The recent Environmental Science Services Administration investigation of the Gulf Stream has been closely coordinated with the long-term Navy-sponsored ocean science research programs of this current system to the mutual benefit of all investigators. The development of buoy systems under the Navy Ocean Science Program also has contributed to other agencies such as the Coast Guard in its development of replacements for light stations. Through such cooperative investigations and translation of benefits from the Navy Ocean Science Program to the civilian agencies, the Navy has attempted to make results of research required for its needs available to others.

Participation in International Ocean Science

While the Navy Ocean Science Program has been mostly oriented toward the development of U.S. groups, its contributions to the study of the world oceans have not been limited to domestic programs and capabilities. In a science which promotes cooperation among nations, the Navy has played a significant role in developing international programs and groups, with the belief that their improvement will contribute knowledge of the oceans of value to the Navy and the nation.

The Navy has been a staunch supporter of the various international cooperative investigations that have been undertaken over the last decade. The support has been through direct participation by Navy groups as well as support of other U.S. scientists. Commencing with the International Geophysical Year in 1957, the Navy has been either directly or indirectly involved in such studies as the International Indian Ocean Expedition, the International Cooperative Investigation of the Tropical Atlantic, the Cooperative Investigation of the Kuroshio,

and the recently initiated Eastern Tropical Pacific (EASTROPAC) investigation. Through participation in such investigations, the Navy Ocean Science Program has been able to acquire detailed knowledge of vast areas of the world oceans which neither the Navy nor the United States could reasonably hope to obtain alone.

Besides collaborating with foreign scientists in international cooperative investigations, the Navy also has assisted in developing a number of foreign scientists and groups through the support of their research in its formative period. Through cooperative programs involving U.S. scientists, the Navy also has contributed to the efforts of other countries in the process of developing and improving their oceanographic programs. Several such cooperative investigations have been conducted with Latin American countries. Long-term ecological studies of local conditions at a number of locations outside of the U.S. also have further contributed to the development of local ocean-science programs. Such studies have been carried out in the Mediterranean-Red Sea area, off the Atlantic coast of Spain, and in the North and Caribbean Seas. In 1965 the First Inter-American Conference of Hydrobiology of Naval Interest was sponsored by the Navy to encourage closer cooperation between the United States and Latin American countries. Since most of the results of ocean-science programs are available to the world, the development of such local efforts by the Navy provides a broad geographic scope.

THE NAVY OCEAN SCIENCE PROGRAM

The Navy Ocean Science Program covers all aspects of scientific investigations at sea. It includes research in physical oceanography, chemical oceanography, air-sea interaction, geology and geophysics, oceanic biology, ocean engineering, and the development of facilities, instrumentation, and equipment.

The basic rationale behind the oceanography program of the Navy is that the oceans provide the environment in which the Navy lives and works. The Navy must have extensive knowledge of this environment and understand the how, when, and where of changes in it. The ocean-science program has the responsibility to encourage new understanding and knowledge to this end.

The types of work in the Navy program include fundamental research, applied research, and advanced development. Each of these is necessary to meet the immediate as well as the long-term needs for the Navy's operations at sea, and each contributes to the others in terms of data, knowledge, and guidance.

The following descriptions present the major parts of the program.

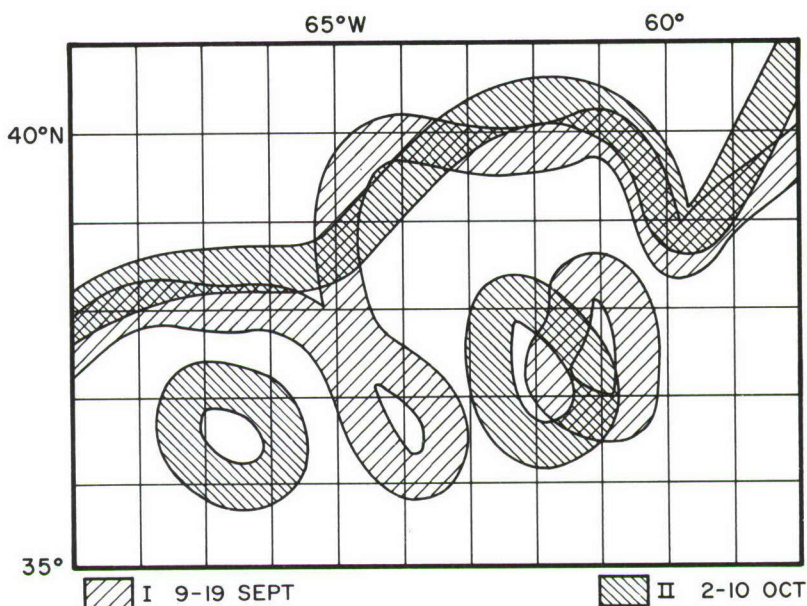
PHYSICAL OCEANOGRAPHY

The objective of research in physical oceanography is to provide accurate descriptions of physical conditions of the oceans, to forecast these conditions on all temporal and spatial scales that may have relevance to naval operations, and to predict the modifications of the physical environment that will result from natural forces or from the activities of man. The research in physical oceanography covers a spectrum of study areas that range from capillary waves to the dynamics of major current systems.

The major water masses of the world ocean have been delineated. From this information, a basic understanding of the

sound-propagation conditions that influence sonar operations can be derived. These descriptions of water masses, however, usually have been limited to average conditions derived from observations of physical and chemical properties obtained over many seasons and years. Large-scale investigations are now being conducted in the North Atlantic and North Pacific Oceans to determine in greater detail the dominant factors influencing both the geographic and temporal variations observed in the water mass and current structure of these oceans. From these studies, second-generation problems for further investigation also are being developed. Such problems concern the mechanisms of water-mass formation and locations in the world in which such formation occurs, the flow of these water masses and the modifications which occur to them during their transit through the oceans, and external environmental conditions which contributed to unique events such as the El Niño condition of warm-water penetration southward along the west coast of South America. New techniques, including the use of biological indicators, are also being explored and developed to aid in the tracking of specific water masses and currents for these studies.

The major current systems are being systematically investigated, in many cases by joint efforts of several groups working on a single current. The emphasis is upon the delineation of the general features of both surface currents and subsurface currents, as well as their variability with time and location. Studies are being conducted to learn more about the Kuroshio current, the equatorial current systems of both the Atlantic and Pacific, and the Yucatan current and its influence upon the waters of the Gulf of Mexico; but the principal object of research on ocean currents is the Gulf Stream system. The research on this system extends from the Straits of Florida to the waters east of Cape Hatteras. A variety of methods are being used to determine its general features and variability. The depth and structure of the flow, as well as the development and persistence of eddies developed from the Stream, are being measured from ships, aircraft, and instrumented buoy systems.



Gulf Stream current meandering pattern and eddy development during a one-month period

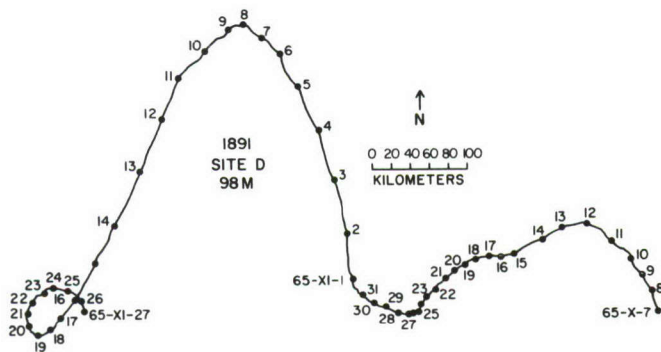
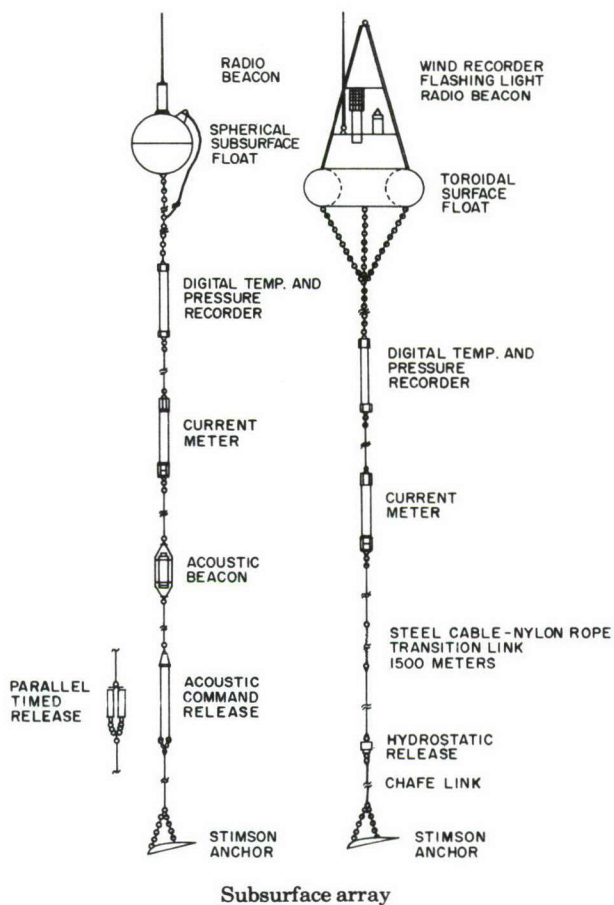
The Gulf Stream study is a long-range program, involving participation of several Navy in-house and academic groups as well as other federal agencies. The program is aimed at contributing not only to a better description of ocean currents but also to theoretical and laboratory studies. The theoretical development of models of ocean circulation actually needs to be augmented by more refined field experiments, and such experiments are being developed. The necessary instrumentation is being evolved. Simultaneously, investigations of the modes of motion in ocean waters, the time and space scales that contain significant kinetic energy, and the coupling of various modes and scales of motion are being pursued. This aspect of the program is in its early stages of investigation, and results from it are expected to contribute substantially to the prediction of current movements which affect navigation and the emplacement of naval systems and equipment in the ocean environment. Because of the influence of currents upon the temperature

structure of the ocean, the results also will aid in predicting the temperature regime of the ocean.

The temperature structure of the ocean, particularly within the surface layer, greatly influences the propagation of sound and the operating conditions for submarines, and likewise acts as an important factor influencing the maritime meteorological conditions encountered by all naval surface and air units. The study of temperature structure within the Navy Ocean Science Program includes the statistical analysis of many temperature-depth profiles obtained from bathythermographs to derive an understanding of the geographic and temporal variations observed. This analysis is aimed at the development of prediction methods. Temperature-anomaly patterns observed on the sea surface of the North Pacific Ocean also are being investigated to determine the causes for their formation and movements.

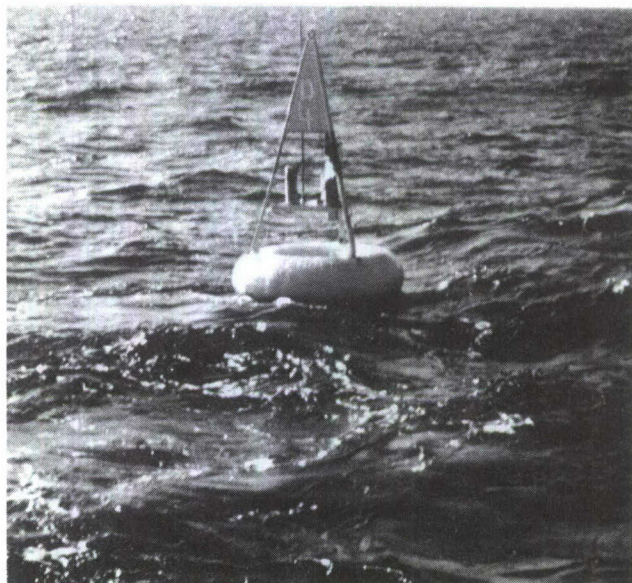
The meteorological and solar influences which contribute to the loss or gain of heat across the ocean's surface layer, such as evaporation and condensation, conduction of sensible heat, and radiation, are being studied both separately and collectively. These studies involve the temperature structure at the very "skin" of the sea surface, as well as throughout the water column within the upper layers of the ocean. The convective and turbulent processes that contribute to the distribution of heat within the water column are being studied theoretically as well as with laboratory models and field experiments. Other programs are concerned with the location, persistence, and structure of thermal fronts in the oceans. These fronts are of particular interest to the Navy because of the discontinuity in thermal structure and, in turn, acoustic-propagation conditions.

The study of ocean temperatures also is closely coupled with that of internal waves, which have a marked effect on acoustic propagation and submarine operations. Through the measurement of temperature from thermistors towed from ships and fixed to towers and buoy arrays, internal waves and the factors which govern their generation, propagation, and decay are being examined in shallow and deep-water areas. Both laboratory and theoretical efforts supplement these field programs, to provide a broader understanding of this important phenomenon.

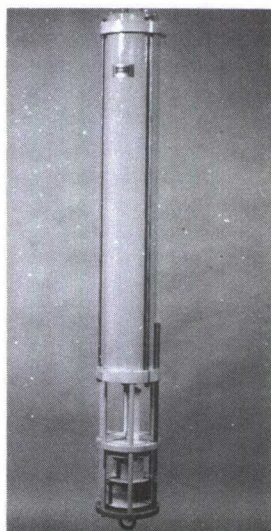


Analyzed current record

Moored buoy system for measuring current speed and direction

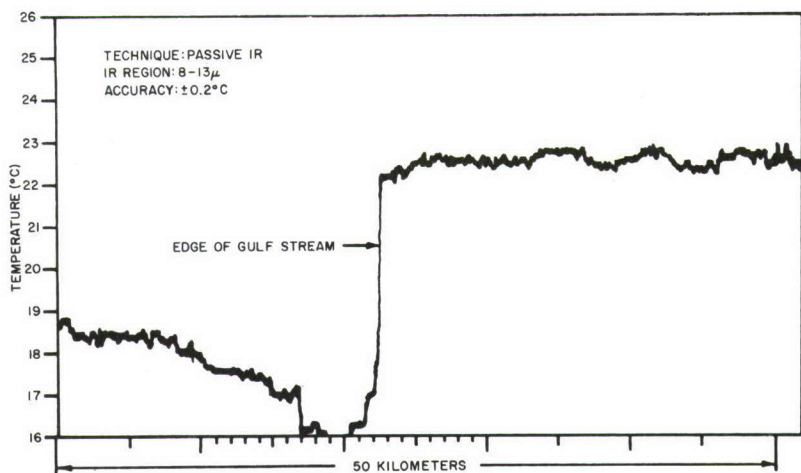


Surface buoy

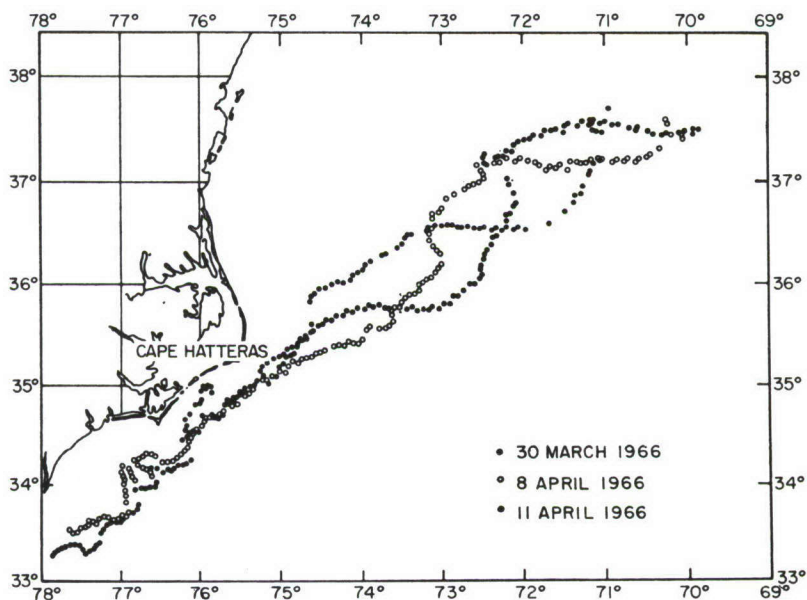


Current meter

Moored buoy system for measuring current speed and direction

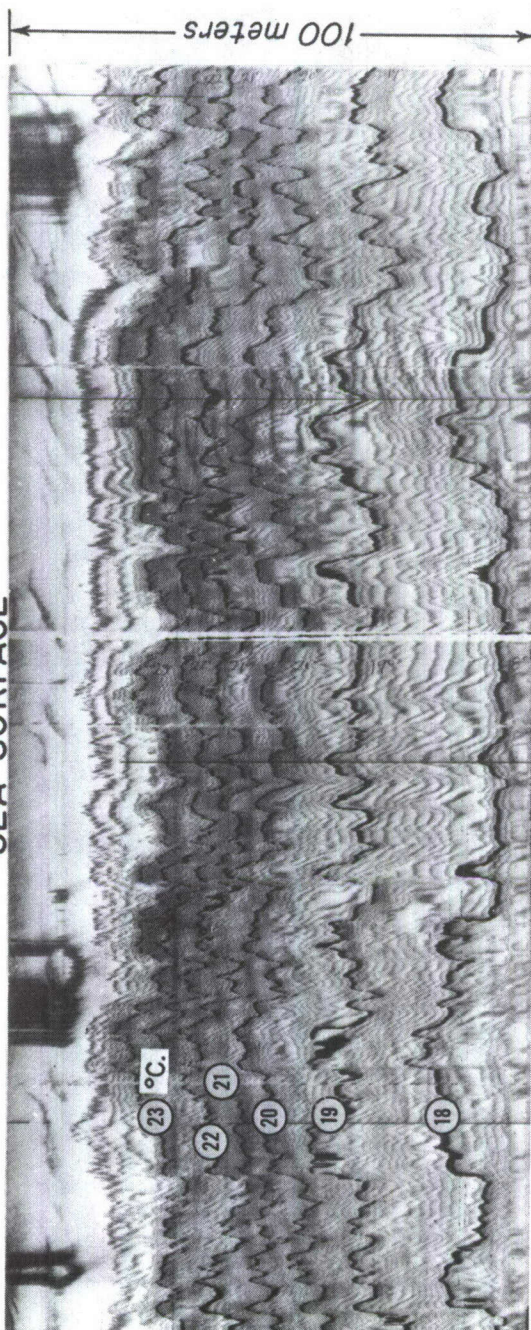


By using an airborne radiation thermometer to determine sea-surface temperatures, it is possible to delineate major oceanographic features such as the Gulf Stream system. The sharp inshore temperature gradient on the northern edge of the Gulf Stream is shown.



The location and tracking of the northern edge of the Gulf Stream by airborne radiation thermometry enables the surface meandering patterns to be defined.

SEA SURFACE



Temperature-structure record of the surface layer of the ocean, obtained from a thermistor chain towed from a research ship

The study of ocean surface waves within the Navy Ocean Science Program covers the spectrum from capillary waves to tidal waves. Capillary waves produce sea clutter on radar systems besides playing a role in the generation of wind waves. Their properties, including their directional spectra, are being determined.

The theoretical problems of the growth, propagation, and decay of wind waves are subjects of continued intensive investigation. An understanding of wind-generated surface waves is necessary for almost all naval operations involving surface ships, for they adversely affect aircraft-carrier operations, refueling and replenishment, and the transit of ships across the oceans. From the viewpoint of sonar systems, they produce unwanted noise and, in addition, scatter the acoustic energy used for the detection of submarines. Our ability to predict the wave field of the ocean has increased substantially in recent years. Attempts are being made to remove some of the empiricism that still remains in the prediction of the growth of the wind-wave spectra and to develop better understanding of the mechanism of wave generation, through a combined theoretical laboratory and field effort.

The study and prediction of tides in the open ocean also is included in the Navy Ocean Science Program. Instruments developed for measuring minute fluctuations in pressure at the sea floor have enabled scientists to embark on a project to resolve the local tidal variation in sea level. At the same time, a new interest in the possibility of obtaining numerical solutions for the tidal oscillations within ocean basins has developed. Studies of the ocean energetics and of internal waves also make it clear that the tidal oscillations are important modes of ocean motion.

CHEMICAL OCEANOGRAPHY

Knowledge of the chemistry of the marine environment is required in support of long-range weather prediction, undersea warfare, man-in-the-sea projects, use of deep-submergence vehicles, preservation of materials, and radiological safety.

The complex organic film on the sea surface has been found to affect the rate of energy exchange through the sea surface. Although water passes through this film and evaporates, and cools the surface, the large molecules of the film appear to stabilize the water underneath the surface and prevent convective heat transfer from the body of the water, thus steepening the thermal gradient. Complete understanding of this phenomenon is necessary for measuring heat exchange through the surface by, for example, aerial reconnaissance. The same film presumably is important in the formation of slicks and visible wakes.

Studies of the ratios of deuterium to hydrogen and of oxygen-18 to oxygen-16 in the compound water are leading to a revision of the rates and energetics of evaporation and condensation close to the sea surface. These ratios also will have to be taken into account in estimating the total energy exchange and its subsequent effect on the prediction of environmental conditions both in the ocean and the atmosphere.

It has just recently become possible to measure directly the velocity of sound on a convenient, reliable, accurate, routine basis. However, the instruments for accomplishing this measurement are still being developed, and demonstrations of their stability and performance for widespread use are still necessary. Such confirmation is dependent upon the accurate measurements of temperature and salinity. The desired accuracy is such that studies of the relationships between these quantities and other physical properties, such as gas content and the compressibility of sea water, must continue.

The dissolved gases in sea water, notably oxygen, nitrogen, ammonia, methane, and hydrogen sulfide, are being measured by gas chromatographic methods. The relative concentrations of these gases yield information about the history of the water and about biological activity. Knowledge of these ratios is important in planning installations, use of some materials, or operations in waters where the oxygen content is low, and especially when hydrogen sulfide is present. Extension of man-in-the-sea programs into some areas, and plans to obtain breath-

able air by exchange with sea water, will require adequate knowledge about the amounts and variability of these dissolved gases.

Direct measurements are being made of the alteration of minerals, for example, the rate of solution of calcium carbonate and of the hydration of volcanic glass in the deep sea. These measurements are of interest in connection with studies of formation of the characteristic minerals of the sea bottom and the history of the sea. They also indicate some of the processes to which man-made installations will be subject.

The path of nuclides from fallout from nuclear events of recent decades is being followed in the sea as a key to long-term mixing downward from the surface. Certain nuclides accumulated by organisms (strontium, cesium, silver) are being followed in the marine biosphere to obtain an indication of the relationship of this pathway to the total circulation. Along these lines, an interesting investigation is pursuing the movement of lead from automobile fuels through precipitation into the sea.

Methane and other short-chain hydrocarbons and hydrogen sulfide are found in high concentrations in some marine environments, such as deep fjords and the basin of the Black Sea, where water circulation is restricted. These substances are inimical to most forms of life, and if for any reason oxygen becomes available, hydrogen sulfide becomes converted by bacterial action into corrosive sulfuric acid. Large volumes of ocean waters at moderate depths in some areas of the open ocean are characterized by a low oxygen content. It can be anticipated that there are localities where there is no oxygen, and where hydrocarbons or hydrogen sulfide might occur. Knowledge of such conditions is important to long-term Navy requirements for erecting structures on the sea floor.

MARINE GEOLOGY AND GEOPHYSICS

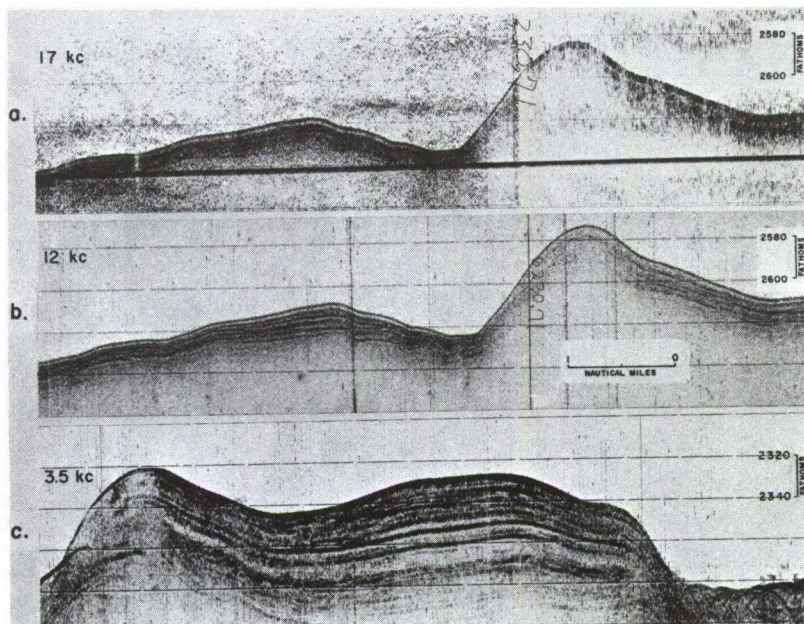
The shape of the ocean floor and the physical and chemical properties and geologic structure of the sediment and rock down to several kilometers below it are the concerns of this

program. These characteristics affect the transmission of sound and the magnetic and gravitational fields of the earth. Thus they influence sonar-system design, undersea warfare, and the operation of deep submersibles. Other properties of the sea floor also affect the design, installation, and maintenance of underwater engineering structures and influence rescue, salvage, and man-in-the-sea operations. Knowledge and interpretation of sea-floor topography are a major accomplishment and are discussed more fully in the section titled "Major Accomplishments."

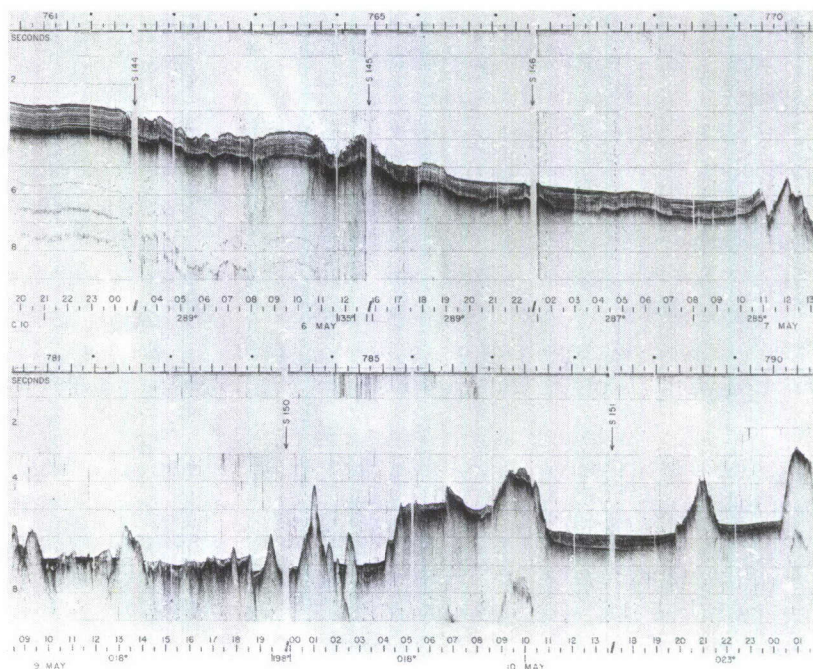
Geophysical investigations at sea are being conducted over a variety of structural types in many geographic areas to determine sediment distributions, thicknesses, and acoustical and other physical properties. These types include mountains, trenches, abyssal plains, long escarpments, sea mounts, and continental rises, slopes, and shelves. Structures and thicknesses of the sediments are determined principally by seismic reflection methods. Seismic profilers, including energy sources such as the electrical "sparker" or the more recent pneumatic "air gun," are used. Low-frequency echo sounders are also being used successfully to determine the structures of the upper sediments.

Since sediment thicknesses considerably affect the performance of sonar systems, the thicknesses have commonly been measured down to the underlying crustal rocks. The measurements also provide knowledge of the sediment structures, deformation, geological history and, to a lesser extent, composition and rates of sedimentation and erosion. Valid interpretations are now beginning to be made on the worldwide distributions of these sedimentary layers. Until 1965 emphasis had been on the delineation of structure, but in the past two years there has been growing emphasis on the measurement of energetics so necessary to sonar design and potentially useful in geological interpretation.

Cores and dredge samples are collected as data for the deliberate study of specific geological provinces. They are returned to the laboratory for detailed measurements of physical and chemical properties, as well as to determine deposition rates



Vertical sections of sediments beneath the ocean floor in the Blake-Bahama area (North Atlantic Ocean), as obtained with echo sounders at sonic frequencies of 17, 12, and 3.5 kilocycles. Records *a* and *b* are along the same traverse. Record *c* is along a different traverse, but over a similar sediment section. The lower frequencies provide deeper reflections within the sediment section.



Vertical sections of sediments beneath the ocean floor in the southwest Pacific Ocean. The top chart shows the northeast flank of the Solomon Rise, and the bottom chart illustrates the Central Caroline basin and south flank of the Caroline Ridge. Records were obtained with a seismic profiler, using an "air gun" source and a towed array of receiving hydrophones. The sections show folding, faulting, and differences in thickness within the sediments.

and the types of mineralogical and biological materials. The objective is to understand the mechanisms which are responsible for the movement and deposition of sediments so that their influence on existing and future Navy systems may be predicted. One of the more significant recent discoveries from cores in high latitudes is that successive layers of clays exhibit reversed magnetic polarization. The clays were deposited over a time when the earth's magnetic field apparently reversed polarity several times. The reversals in the cores have been correlated with reversals of known age in lava beds on land. The core reversals may thus have application to dating ocean sediments. This finding has inspired renewed activity in magnetic studies of sediment.

Sediment transport occurs by a variety of mechanisms. Many sediments are turbidites, which were transported by turbidity currents for extraordinarily long distances. Sediment is also being found suspended in layers in ocean water. Optical measurements in the deep sea have shown that a very small amount of suspended sediment exists in these (nepheloid) layers, particularly near the bottom. These layers appear to provide an important and previously unknown process for sediment deposition in the deep oceans. Such layers have been identified in various regions, but particularly off the east coast of the United States, the Aleutian Trench, and the eastern Pacific. Wind-carried dust also provides a transport mechanism. This comparatively recent series of findings provides new insight into sediment transport processes, the full effect of which can be assessed only as the program is continued. Analysis of dusts collected in the Atlantic in low latitudes shows them to correlate with terrestrial samples from Europe and Africa. In the Atlantic at low latitudes, these materials appear to be transported by trade winds. Sediment cores that include materials deposited prior to and following the last ice age have been analyzed to determine indicated climatic conditions and variations in composition and deposition rates.

Sediment ages are determined primarily by the potassium-argon method, by fossils, and by correlation of volcanic ash

layers. It recently has been shown by the potassium-argon method that deposition rates measured in cores of sediment in parts of the North Pacific are millimeters per thousand years. This is comparable to present-day rates. Identification of volcanic ash beds from historical eruptions of volcanoes have established rates as high as one meter per thousand years in the western Mediterranean Sea, an area with a potentially huge supply of detritus. Studies on orospherid radiolarians (siliceous skeletons of spicules) in sediments show that these fossils were laid down rapidly during the Tertiary period, and therefore may be useful in assigning stratigraphic ages to otherwise unfossiliferous ocean sediments. Other investigations have shown that the oldest sediments in the ocean deeps are more than 100 million years old; the previous oldest identified age was 70 million years. These and other means of dating are being used in an exciting race to establish the major framework of the history of the ocean basins. The seismic-reflection profiler has supplemented these methods by discovering significant outcroppings of layers of sediment or rock that could then be sampled and dated. This program continues very aggressively and is being accompanied more and more by excellent measurements of acoustical properties.

Studies of sediments being conducted along the continental margins are showing the existence of complex structures on both the shelves and slopes. The studies indicate variations in rate of uplift and subsidence, and sometimes indicate how the continent has grown in the seaward direction. It has been shown that continental rocks affect the shaping of the continental shelves and control the distribution of sediments at sea. Studies are being made on the origin and nature of submarine canyons, particularly on the mechanism producing the erosion (the mechanism has not been completely resolved). These investigations, though obviously valuable, are but a mere beginning. We need to know more of the exact shape, stability, and dynamics of the shelf and sloping regions off our continent, both for sonar and for the installation of structures.

Seismic-refraction measurements provide the most reliable determinations of thicknesses of crustal layers in the earth,

on depth to the mantle, and on mantle seismic velocities (see "Sediment and Crustal Structure" in "Major Accomplishments" section). These crustal layers affect the propagation of sound of very low frequency near and in the infrasonic frequency range. Their study continues to be an important component of this program.

Variations in crustal and mantle structures produce anomalies in the earth's gravity field which, at sea, are important to navigation, particularly in determining the shape of the geoid (approximate sea level surface) and the deflection of the vertical (angular difference between the normals to the geoid and the earth's reference ellipsoid). Gravity at sea also provides significant information on crustal and mantle rock configurations and, therefore, on processes that shape the ocean floor, thus aiding in the interpretation of geologic structure.

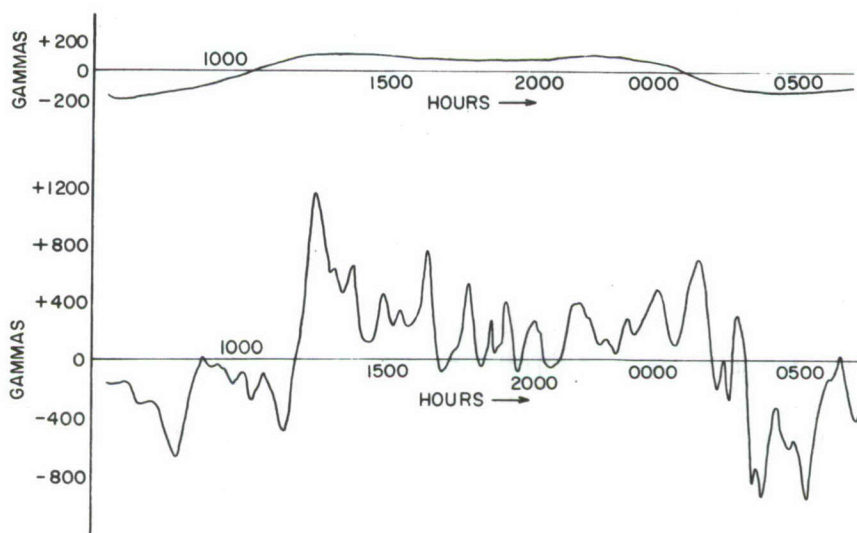
Gravity measurements at sea were first made with pendulums in submarines and later with spring-balance gravity meters in submarines. Since about 1963 reliable measurements have been made with gravity meters on surface ships, which are now accurate to about ± 5 milligals; it is anticipated that this accuracy can be increased to ± 1 milligal with the advent of navigation satellite control and with improved gravity meters. Regional gravity anomalies being obtained from surface-ship measurements correlate reasonably well with those based on satellite measurements.

Crustal and mantle structures are being analyzed on the basis of marine gravity measurements, particularly off Oregon, Hawaii, the Solomon Islands, the Mid-Atlantic Ridge, and various abyssal plains and island arc trenches. Anomalies are found to be associated with geologic structures; they frequently correlate with bottom topography, but there are many marked exceptions, some of which have been satisfactorily explained by density distributions suggested by seismic data.

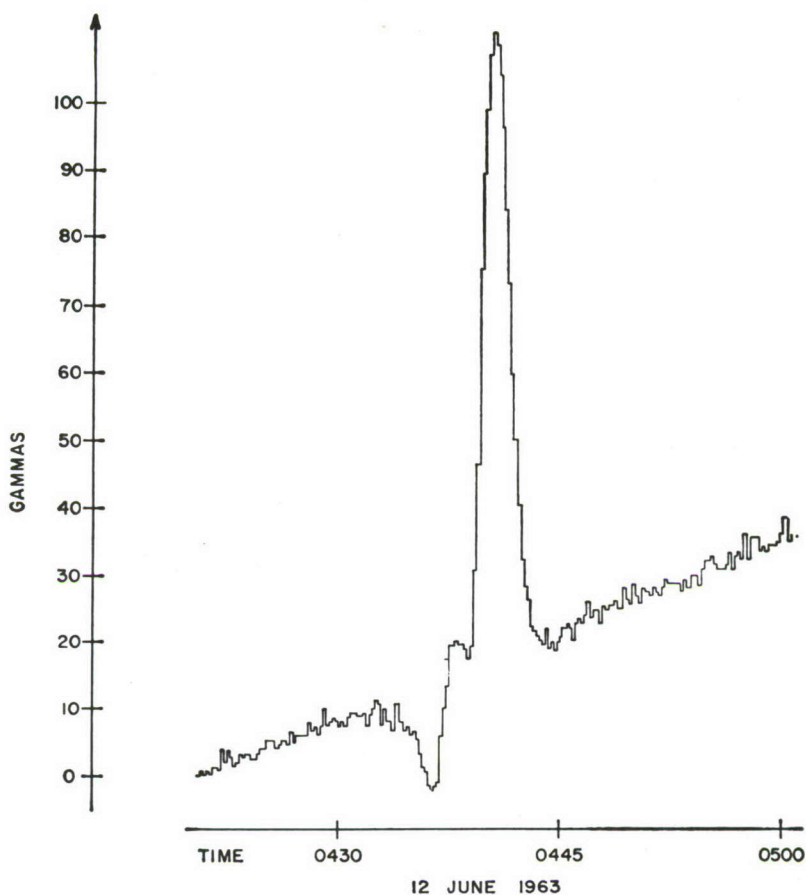
The gravity program is fundamental to knowledge of the shape of the earth, and it is a matter of military importance. It also is useful as an interpretive tool with other geophysical data.

Magnetic measurements have been made at sea for many years, but for over two decades excellent measurements of the magnitude of the total field have been possible. Magnetometers towed by aircraft and located in a fish towed behind a ship provided the earlier means of measurement. Magnetometers are now being towed near the sea floor as well to detect small variations in the magnetic field associated with crustal rocks, and to locate man-made objects such as submarines or sunken ships. Such a deep-towed magnetometer helped investigate the THRESHER disaster.

The magnetic data are being used primarily for interpreting crustal structures. Recent measurements have provided the main evidence for sea-floor spreading, the current concept of great interest that the sea floors are spreading laterally away from ocean ridges. Surprisingly, it has been found that the magnetic-field variations over ridges in different oceans are quite alike, even in detail. Another recent finding is that oceanic ridges have been displaced laterally by a series of faults.



Profiles of magnetic anomalies measured on the sea surface (upper graph) and measured near the ocean floor (lower graph)



Profile of magnetic anomaly over THRESHER as recorded near the ocean floor, during passage over the wreckage

Further development of our knowledge of the magnetic field of the earth is an important concern of the Navy, particularly for use in search-and-salvage operations and in undersea warfare.

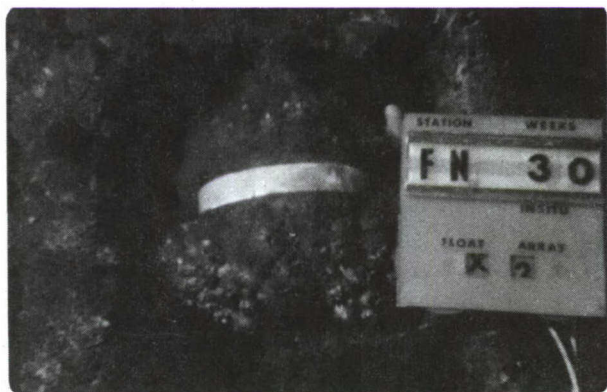
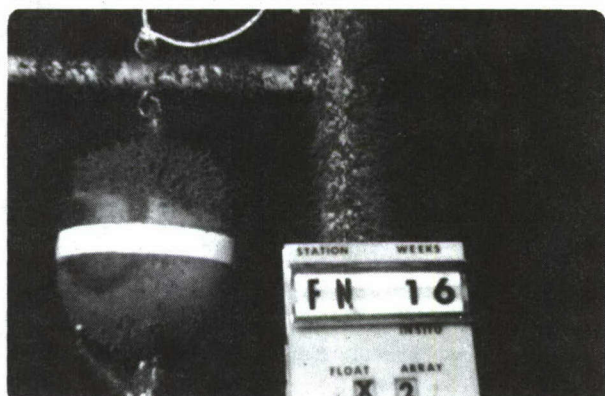
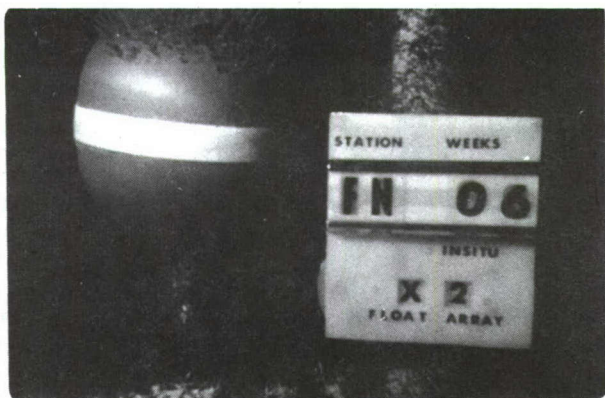
Heat-flow measurements are being made at varied locations in the oceans to indicate processes occurring in the underlying crustal and mantle rocks. It has been found, quite unexpectedly, that the average heat-flow rates in the oceans are nearly the same as average rates in the continents, despite the thicker continental crust with a higher concentration of radioactive

elements. Somewhat systematic variations in heat-flow rate have been observed in different types of oceanic structures. On ocean ridges the heat-flow rate is usually two to six times the average oceanic value; in ocean trenches the value is below average. The importance of this program to the Navy is indirect, in that its results aid in the interpretation of submarine geological structure. Another indirect benefit is the measurement of temperatures of bottom waters that has come from the temperature sensors used in this work. This program is clearly an adjunct to other continuing geophysical programs and will be continued as such.

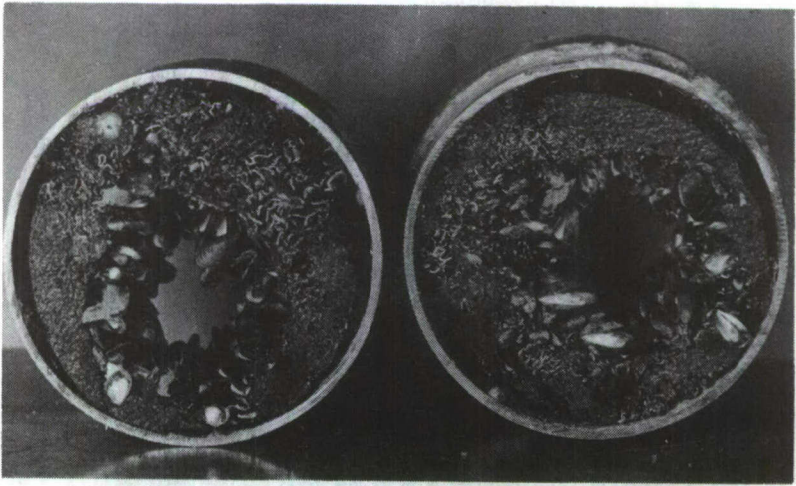
OCEANIC BIOLOGY

The biology and ecology of organisms affect such Navy problems as fouling and deterioration of equipment, man-in-the-sea experiments, acoustic propagation, and others. The nature of these organisms, their effect and control, and prediction of their distribution seasonally and geographically is needed to prevent or minimize adverse effects on Navy operations. Work conducted or supported by the Navy is concentrated on organisms and environments of particular interest.

As result of investigations made on fouling, biological deterioration, and corrosion, it is now possible to predict the rates and kinds of infestations that occur in waters of known properties and in particular geographic regions. Worldwide collections are made of marine boring and fouling organisms. Active and destructive boring organisms appear to be abundantly present, even at depths of 2000 meters, and fouling organisms were obtained in deeper waters than expected. Test results in one deep area show that bacterial slime attaches to most plastics and ropes; that marine organisms cause deterioration of cotton and manila ropes; that molluscan borers attack wood panels and manila ropes; that some marine organisms cause deterioration of cable insulating material; and that untreated wood is susceptible to total biological deterioration. Materials that have shown little or no biological deterioration include various types of rubber, nylon, Teflon cable insulation, and glass.



Fouling on a float after 6, 16, and 30 weeks



Section of six-inch pipe formerly located over the boiler of a Navy ship.
The pipe is almost closed by fouling marine growth.

A project of long duration is the study of false acoustic targets in the sea caused by large mammals and by schools of fish, which return echoes and otherwise appear similar to ocean-bottom and military targets. This work involves recording echoes obtained under various environmental and experimental conditions, analyzing them in frequency, amplitude, and time, and developing conclusions which can be used by fleet personnel during operations or equipment development. Closely related to these studies is the collection of accurate information, including recordings of the sounds produced by marine animals, the geographical and seasonal distribution of the sound producers, and the habits of the animals which are significantly related to sound production. The organisms range from whales and porpoises through numerous fish to invertebrates, including notably snapping shrimp.

A newly constructed audio-video laboratory has permitted investigations on biological acoustics. From these studies it has been shown that sharks can detect and respond to a wide range of sounds, and that they are attracted rapidly to a series of sonic pulses. An observation chamber that can follow a school of



Divers installing an underwater television camera for monitoring fish behavior, in the Straits of Florida off the west coast of Bimini, Bahamas, in water 60 feet deep. This camera is cable connected to a television monitor and video tape recorder in a laboratory ashore. By means of a rotatable-tiltable mirror, the camera can be panned through 360 degrees and tilted through 70 degrees from the shore laboratory. Focusing and the operation of a zoom lens can also be done from the laboratory.



Underwater television monitor observation of a school of margate assembled in the early morning hours

cetaceans in the oceans has been tested and is to be used to investigate the behaviorial patterns and reactions of porpoises.

Studies are being made that combine acoustics and optics. Plankton, that is, small floating or feebly swimming animals that occur in dense clouds, scatter both sound and light and have an effect like fog on a display system. Plankton, other small organisms and accompanying predatory fish appear to be the principal sound scatterers. Their target strength and resonant frequencies are investigated, as well as their distribution and variation with season. Many species spend daylight hours at depths of a few hundred fathoms and disperse toward the surface at night, but the full particulars of their behavior are not known. All of these characteristics limit the effectiveness of sonar operations.

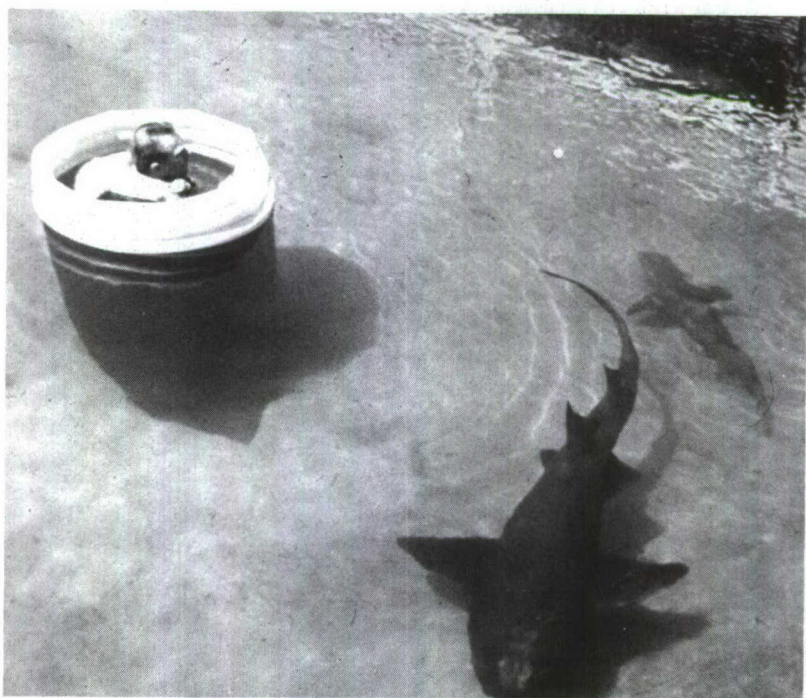
As light scatterers, plankton reduce the range of vision for photography underwater. Hence, they hamper construction and salvage operations where divers, photography, or closed-circuit television are used. Some plankton present the Navy with special

problems because they light up when disturbed. A surfaced submarine at night may be surrounded by a brilliantly glowing halo of foam. Such bioluminescence can sometimes be seen for miles. Research includes identification of the organisms, survey of their distribution, and study of the internal mechanism that pertains to luminescence, its prevention, avoidance of stimulation, or other control measures.

Many marine organisms, especially in warm water, are venomous. Upon being touched, they transfer, through various organs, substances that cause irritation, pain, or more serious consequences. Personnel in the water may be hampered or seriously affected. Study of pathology and development of treatment depend on identifying the organism and understanding its particular venom. Most of the research is done by specialists in different groups who are supported on a part-time basis by the Navy in projects to obtain special information or select and compile information available to them and put it in a usable form.

Tropical fish are the most important of the poisonous organisms. Some are regularly eaten, either with some organs removed, or prepared in certain ways. They are therefore a potential hazard to Navy personnel recently arrived in a tropical area and fond of fish. As in the studies on all other marine organisms, it is necessary to identify each species, learn where and when it occurs, provide means of recognizing and avoiding it, and collect information on the conditions, if any, under which it can be safely eaten.

Research on protection of personnel against predatory animals basically consists of determining how to avoid needless exposure to danger, how to escape an attack or threatened attack, and how to exclude or drive away the dangerous animals. Studies have resulted in providing recognition criteria, charts of distribution, and critical summaries of accumulated experience of divers and others. One application from these investigations had led to a "plastic shark bag." A survivor can climb into the bag, thereby preventing body fluids and other attractants from being dispersed into the water. Preliminary tests are being made to determine the effectiveness of the bag.



An experimenter afloat in a plastic bag exposes himself to potential shark attack. The bag and flotation rings fold into a small package that can be attached to a pilot's life jacket.

UNDERWATER SOUND

Within the body of the ocean, sound becomes the only practical means for sensing or transmitting information beyond a few feet. Fortunately, sound travels at reasonably high speed (about 5000 feet per second) in water, and the attenuation is not prohibitively great. As a result, most submarine-detection systems, underwater-communication systems, echo sounders, object-location devices, and underwater-guidance systems are acoustic devices. The credibility of our readiness for defense against enemy submarines as well as the operation of our own undersea fleet is absolutely dependent upon making the best use of a sensing mechanism with which the environment seems to conspire to make intractable. The dependence of this important

phase of our defense on understanding of the environmental effects on underwater sound gives an extremely high priority to this phase of ocean science. The dependence of underwater weapon effectiveness and countermeasures on acoustic performance further enhances this priority.

Propagation of Sound in the Oceans

Since the ocean is not a homogeneous medium with plane boundaries, acoustic energy does not travel in straight lines for any significant distance. It is refracted by the varying sound-speed structure of the water masses, scattered by biological or other suspended materials, reflected and scattered at the ocean surface and bottom, and absorbed by the water mass through which it travels. To exploit acoustic phenomena, we must understand the mechanisms by which acoustic energy is transmitted from one point to another at ranges from a few feet to many miles, at frequencies from sub-audio to ultrasonic, and how the transmission process is affected by the oceans and its boundaries. Research is being pursued along lines discussed in the following paragraphs.

The paths by which acoustic energy is transmitted through ocean-water masses of differing temperature, salinities, *etc.*, are being identified and evaluated. This program includes measurement of the acoustic properties of sea water and the structure of these properties within the ocean. It also includes theoretical analysis of the paths followed by sound through the ocean and even beneath it, through sediment and rock, and experimental measurement of sound transmission at sea and in laboratory model studies.

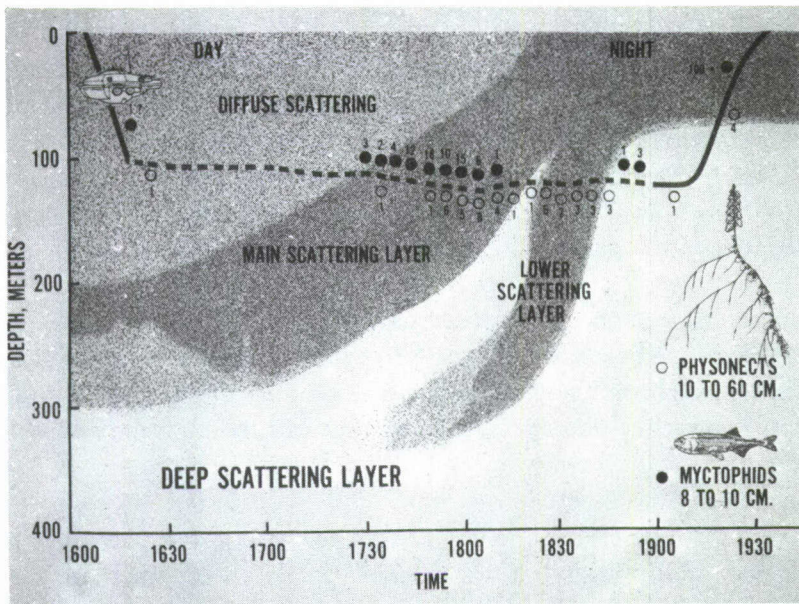
Reflection mechanisms and losses at the ocean bottom are being studied as a function of composition, roughness, and acoustic frequency. The ocean floor has the same general character as the land areas of the world—mountains, plains, channels, canyons, exposed rocks, and very soft muddy areas. Because underwater sound propagation is markedly affected by the ocean bottom and the underlying materials, extensive measurements have been made with an evolving series of precision echo

sounders that have been used on many different ships and in most oceanic areas. These devices have provided relatively accurate data on bottom topography, bottom roughness, and particularly on bottom slopes (see "Major Accomplishments").

The thicknesses and acoustic properties of ocean sediments are being investigated in a great variety of ocean structures and physiographic provinces by means of seismic-reflection methods. These investigations have used explosive and, more recently, electrical, and pneumatic sources; for the upper sediments, echo sounders are being used in the 3 to 12 kilocycle per second range. Thicknesses and acoustic properties of underlying crustal and upper mantle rocks are measured with refraction seismic methods in a wide variety of ocean structures and physiographic provinces.

Measurements are made of the acoustic properties of the oceans and underlying rocks. The velocity structure in the oceans is correlated with different types of water masses and with geographic regions. Flat abyssal plains with sediment fill provide the best conditions for long-range underwater sound propagation. Bottom roughness has the effect of reducing the range of propagation. The effects of hills and mountains is to produce shadow zones in long range propagation.

Scattering and loss of acoustic energy by the ocean bottom, ocean surface, biological material, *etc.*, are a subject of scrutiny. The ocean surface and ocean bottom not only reflect sound but scatter it in all directions. This phenomenon causes a loss of sound energy in the desired direction and causes sound energy to be deflected uselessly. Considerable support for research and measurement of these phenomena form an important part of the acoustic program. Deep scattering layers which cause both loss and scattering of sound have long been known. These layers have been found to consist of several species of marine animals. These animals move vertically, apparently in response to the available amount of light, rising to shallow depths during night time and descending during the day. The identity of these animals is not fully established, and a program is under way to identify and measure the populations of the layers and



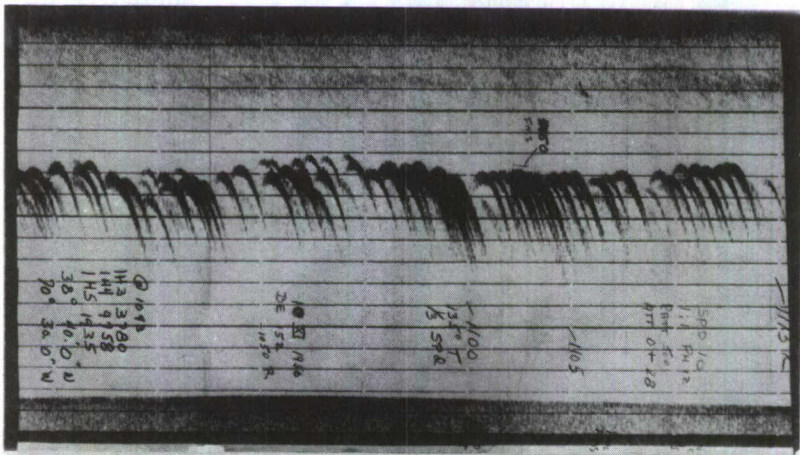
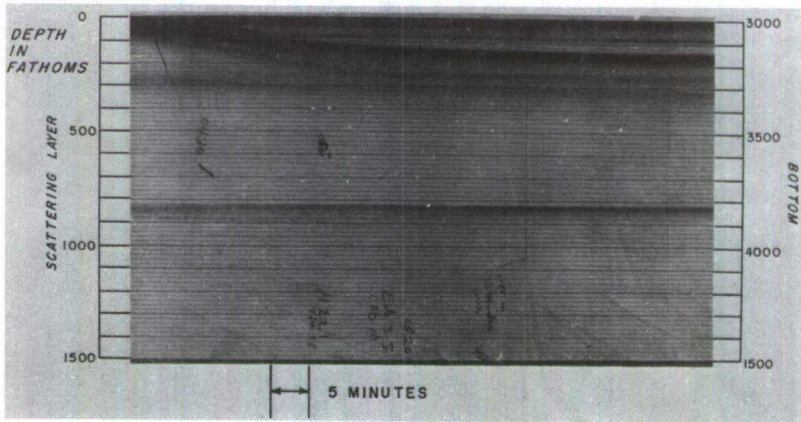
The deep scattering layers scatter sound as from bubbles of gas which resonate at certain frequencies according to their size and depth. Both small fishes Myctophids and Physonects have such gas bubbles for adjusting their buoyancy. The observations made from a diving saucer by Navy Electronics Laboratory scientists show the relationship of these animals to the scattering layer off the coast of California.

to arrive by theory and measurement at its effect on acoustic applications in a much more quantitative sense than is presently available.

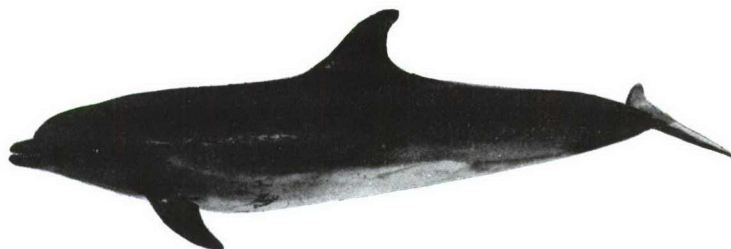
The effects of the variability of the ocean (in each of the above areas) on classes of acoustic transmitting and receiving systems are subjects of study. This subject is discussed further in this report in the section titled "Prospects for the Future."

Noise in the Oceans

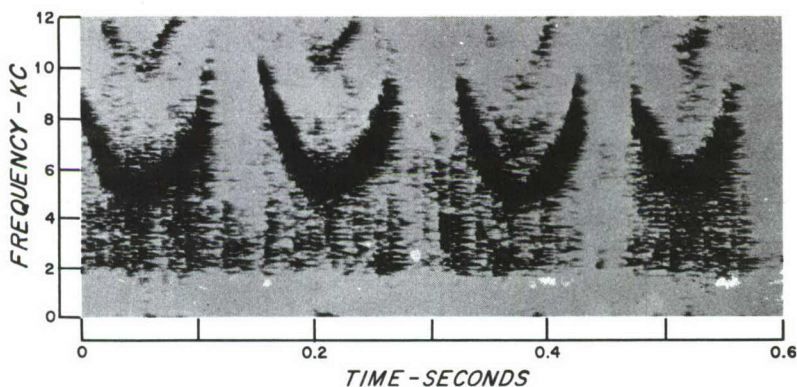
The oceans contain many natural sound makers and many noisemakers powered by man. These sources of sound must be identified in order to understand and predict their effect on communication and detection systems.



At dawn some scattering layers migrate from near the surface to depths as great as 200 to 500 fathoms. Others may not migrate at all, while still others (not shown) rise from greater depth toward the surface at dawn. These two records show animals dispersed evenly in layers (upper record) and others that concentrate in groups (lower record). Echoes of the groups are recorded as the ship passes over, forming a crescent pattern. On both records the echo from the sea floor appears below the layers at nearly constant depth.



TURSIOPS TRUNCATUS—BOTTLENOSED PORPOISE



Sonogram of the bottlenosed porpoise, illustrating the change in frequency of the porpoise squeal as a function of time

The natural sounds include breaking waves, wind, rain, earthquakes (seismic noise), and the sounds of marine animals. While some of these are useably predictable if the weather is known, only limited knowledge is available for either earthquakes or biological sounds. As previously discussed, a significant effort has been placed on the identification of sounds of biological origin. A very large field of investigation remains on these sounds. Seismic noise, a significant concern to naval sonar designers, has received limited attention in this program.

The sounds generated by man are mostly industrial noises transmitted into nearby coastal waters and sounds made by ships and submarines. Since many of the detection-system

concepts depend on these noises to detect and track enemy vehicles, it is important to understand their mode of generation and how it is influenced by the environment.

ENVIRONMENTAL PREDICTION

The long-range goal of most of the Navy Ocean Science Program is to develop the ability to predict the oceanic environment for purposes of naval operations. Such ability may take many forms. It may be the day-by-day prediction of acoustic paths in the sea for the detection of submarines, the forecast of surf conditions on some remote beach for amphibious assault landings, or the prediction of the ocean-floor properties for acoustic or structural purposes.

As a result of research under this program in the past, the Navy now has a capability to predict surface-wave spectra. There are still a number of investigations in surface waves to provide the basic understanding necessary for refinement of the present techniques; but further major improvements in wave forecasting will require extensive networks for the observation of the surface-wind field over the oceans. Nevertheless, the Navy operates a successful ship-routing program based on its present ability to predict ocean-surface conditions.

One of the major prediction systems with which the Navy is concerned is the prediction of time-variable environmental conditions which affect ASW operations. Investigations which bear on this capability include those in the transfer of heat and energy between the ocean and the atmosphere, internal waves and turbulence, and oceanic circulation, including the location of ocean currents. The Navy presently has substantial ASW environmental-prediction systems in operation, but these are based primarily on climatic data and empirical relationships, and much more understanding of the mechanisms involved is required.

Another type of prediction, which depends on an understanding of the processes involved in shaping the sea floor, is that of estimating what the bottom conditions will be in areas which

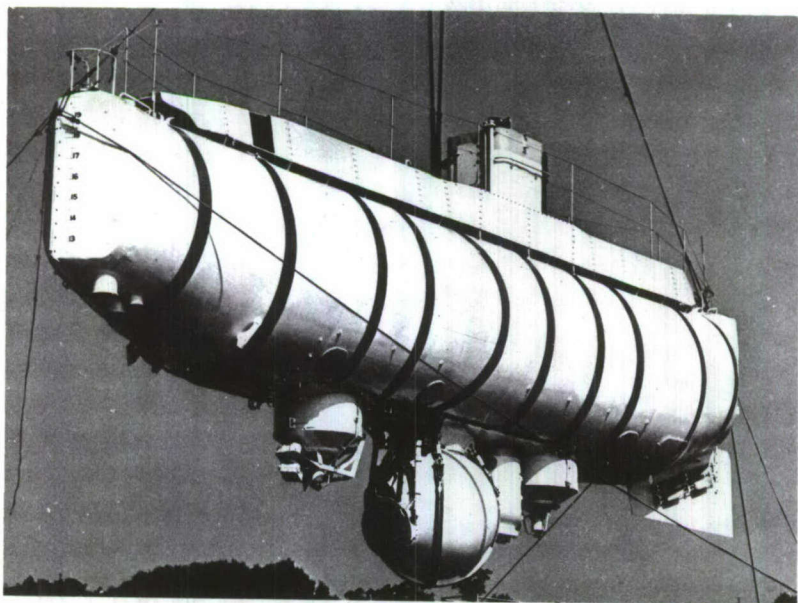
have not previously been investigated or surveyed. A number of investigators are attempting to describe the oceans in terms of geophysical provinces which would permit the estimation of bottom properties in a little-known area on the basis of its similarity to a well-known area, in terms of geophysical and geological similarity and origin. As an example of application, this ability to estimate sea-floor properties and configuration is being combined with the prediction of the time-dependent variables in the water to predict acoustic-propagation paths for several Navy systems.

ENGINEERING RESEARCH

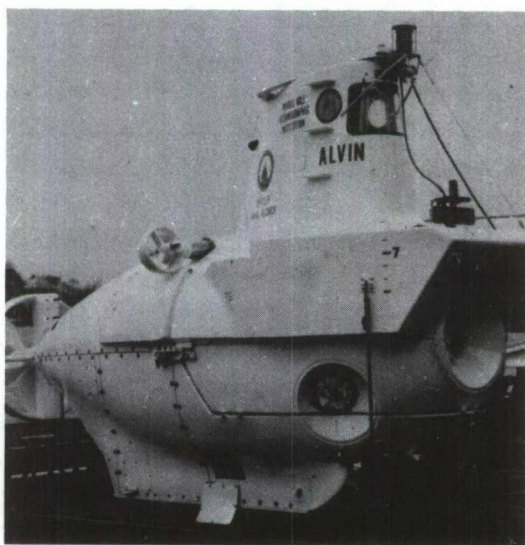
Implicit in all areas of marine science and technology is the requirement to build equipments which perform the required functions with ease, reliability, and low cost. Much of the ocean technology available today came about as a result of individuals providing their own solutions to immediate problems. The current programs are aimed at organizing this effort and providing a broad engineering, science, and technology base to furnish adequate support for all marine science research efforts. The distinction between science and engineering becomes very faint in most areas involved. The general distinction used is that if the effort is directed toward obtaining an understanding of the medium, it is called ocean science; but if the effort is intended to enable man to work in the oceans, it is called ocean engineering.

Deep Underwater Research Vehicles

In 1958 the TRIESTE was brought to this country from Italy. This start has permitted the United States to achieve complete leadership in the deep-vehicle field and has resulted in the development of a whole family of vehicles in the U.S. which range in size from small one-man vehicles to the eight-man ALUMINAUT. In the continual development of deep underwater research vehicles, efforts are underway within the Navy Ocean Science Program to improve materials and structural-design



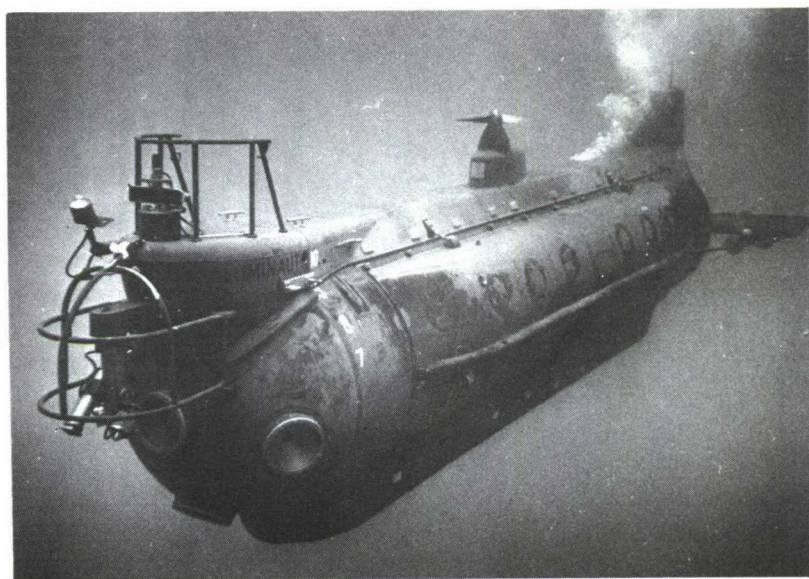
The bathyscaphe TRIESTE, a deep-ocean research vehicle operated by the Navy Electronics Laboratory



ALVIN, the Woods Hole Oceanographic Institution deep-ocean research vehicle for operation to depths of 6000 feet.



CUBMARINE, one of a class of underwater research ships for operation at shallow to intermediate depths along the continental shelf. The maximum operating depth is 600 feet.



ALUMINAUT, a research vessel uniquely constructed of aluminum rings, for operation to depths of 15,000 feet.

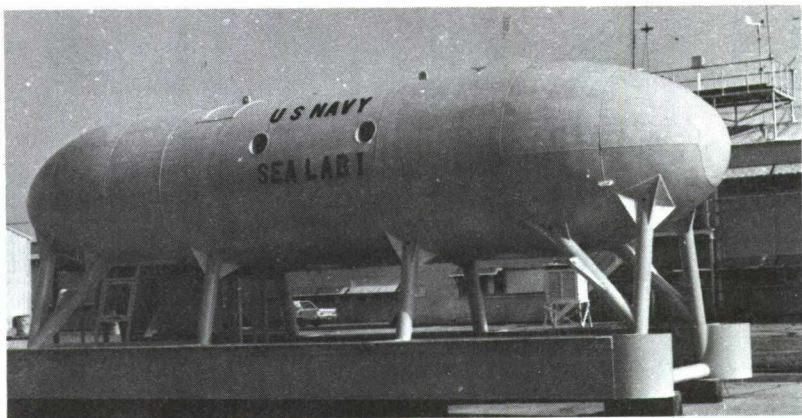
methods. These efforts are to provide vehicle capability for operating at any depth in the ocean with safety. Both high-strength metallic and nonmetallic materials, including glass and composite materials, are being investigated for such use. The techniques of life support, navigation, communications, bottom mapping, photography, and direct viewing also are being pursued to improve further the capability of both existing and future vehicles. An investigation is being made of new methods for providing power for propulsion and life support capable of being operated at very great depths and having high energy-to-weight ratios. The ALVIN, built under the Navy Ocean Science Program, is being operated in an experimental program to determine the best methods for outfitting vehicles. This program also is determining the best methods of using such vehicles at all ocean depths, in the recovery of objects from the ocean floor, and in performing other useful work.

Man-in-the-Sea Research

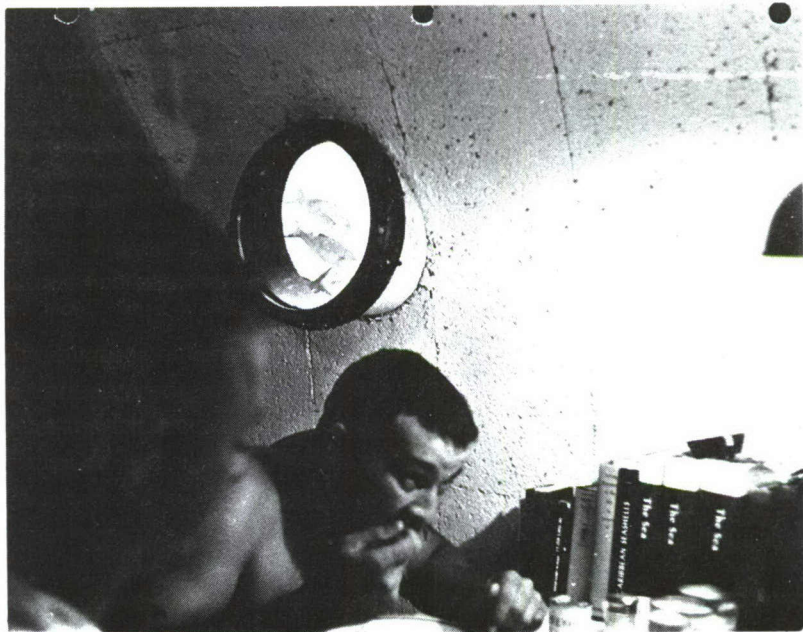
The Sealab I and II experiments were conducted under the Navy Ocean Science Program to assess the basic problem areas in man's ability to live and work for long periods on the ocean floor. The Sealab project itself has been transferred to the Ocean Engineering and Development Program, where work to exploit the man-in-the-sea concept is underway at a high priority. Work is continuing within the Navy Ocean Science Program to further the understanding of the basic physiology of humans under high pressure in artificial atmospheres and to define the basic work functions which a human can perform. The interfaces between the human and work-assist devices (tools), the basic science of life support systems, and other techniques required to place man safely and economically on the ocean floor to do useful work are receiving attention.

Other Areas

The total Navy program in ocean technology is just developing, but already certain ocean-science input requirements are



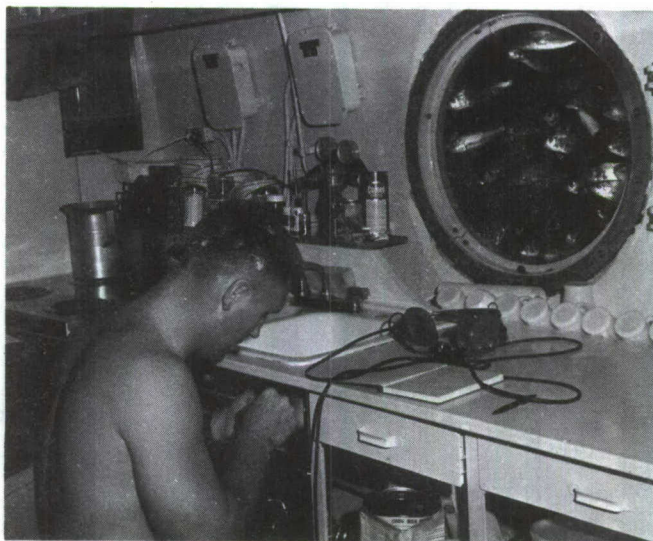
The Sealab I habitat, which housed four men during a stay of 11 days on the bottom of the ocean, at a depth of 193 feet, near Bermuda in 1964



Sealab I aquanauts inside the habitat 193 feet below the surface



The Sealab II habitat, which housed three teams of ten aquanauts for 15 days each off the California coast near La Jolla at a depth of 205 feet in 1965. The conning tower provides access when the habitat is floating on the surface.



An aquanaut repairs a headset in Sealab II under the watchful eyes of the displaced inhabitants.

becoming obvious. Much remains to be done to develop an understanding of the interrelationship of bottom-soil properties with various bottom-penetration methods (pile drivers, coring tools, anchors, *etc.*). Studies of the applicability of new materials to specific problem areas associated with working in the ocean environment also are underway. For instance, a review is being made of the flexibility-strength-weight-corrosion resistance properties of titanium in relation to conventional materials used as mooring and hoisting cables.

A small project concerns a radical new concept of underwater manipulators, using only tension members, and prospectively capable of providing a manipulator of extreme dexterity and zero net weight in water. In parallel with this past effort, research is continuing on the utilization of electronic components in the deep ocean, exposed directly to ocean pressure, to avoid the necessity of large, heavy pressure containers.

INSTRUMENTATION

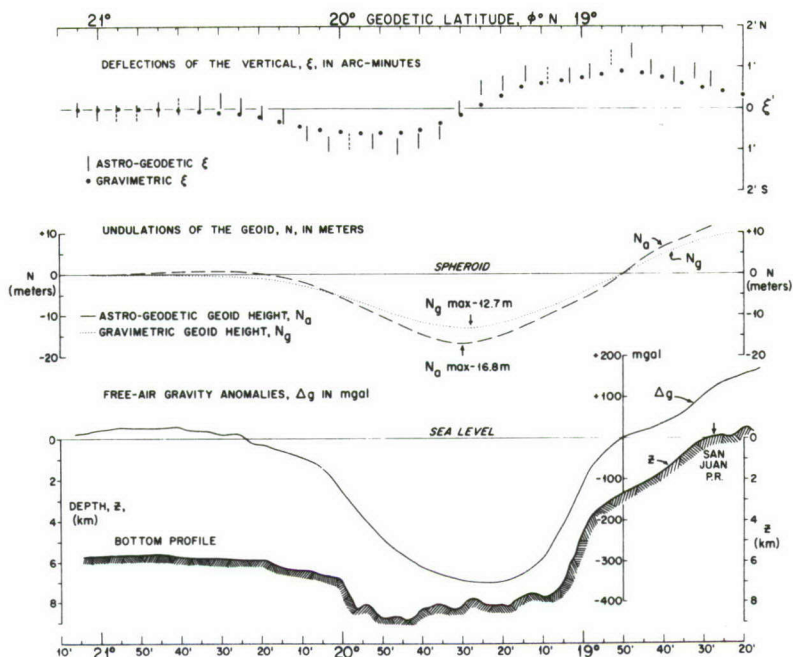
Any progressive science moves forward by the application of the most advanced tools for measurement and provides the impetus for new instrumentation to measure parameters whose importance has newly emerged, or to measure with newly required precision parameters of long-term interest. The Navy Ocean Science Program includes the development of a wide variety of instruments required by the research scientists.

New instruments for making *in situ* measurements from ships are continually being developed under this program. Several deeply towed marine observational systems have been constructed for making detailed and accurate measurements of various aspects of the deep-sea floor. Such systems have application in locating vehicles and other structures at depth, as well as for obtaining scientific data. In one or another of these towed systems the instruments include cameras, magnetometers, sound-velocity meters, and other sensors. Precision navigation for the systems is usually provided by use of expendable acoustic transponders fixed to the ocean bottom.

Major instrumental improvements also are being made for obtaining higher resolution measurements on the thicknesses and structures of sediments and rocks beneath the bottom. These are the seismic profilers employing an electrical "sparker" and, more recently, the pneumatic "air-gun." The principal achievement of these systems is to permit the investigator to maintain continuity of observation of complex and rapidly changing geological structure during long sea passages. The new sound sources also reduce the requirement for using high explosives. New towed hydrophone arrays are being developed to permit these seismic reflection measurements to be made at higher speeds, and buoys to act as receiving hydrophone arrays are being used to permit single-ship seismic refraction and reflection experiments. These instruments are also of importance to the Navy because of its need to study the behavior of acoustic energy in the ocean.

Improvements are being made to gravity meters used aboard surface ships. As a result of the Navy Ocean Science Program, this type of meter has become sufficiently reliable to provide many sorely needed gravity measurements at sea. Further increases in reliability of the gravity measurements are being anticipated at the present time, both because of increased meter accuracy and because of newly improved ship navigation control.

Another device has been under continuing development for determination of the slope of the sea surface from a ship. This determination involves measuring the astronomical position of the ship with a theodolite on a very accurate gyrocompass. The device now provides measurements of the vertical that are accurate to within 10 to 15 seconds of arc. This astronomical position, when compared with the ship's geographic position obtained from navigation data, provides a measure of the deflection of the vertical, and thus departures of sea level from the earth's ellipsoid. The instrumentation is being refined to provide deflection measurements that are accurate to about two seconds of arc. The application of this instrument is important to the Navy's gravity program and holds promise for our knowledge of oceanic circulation based on density structure.

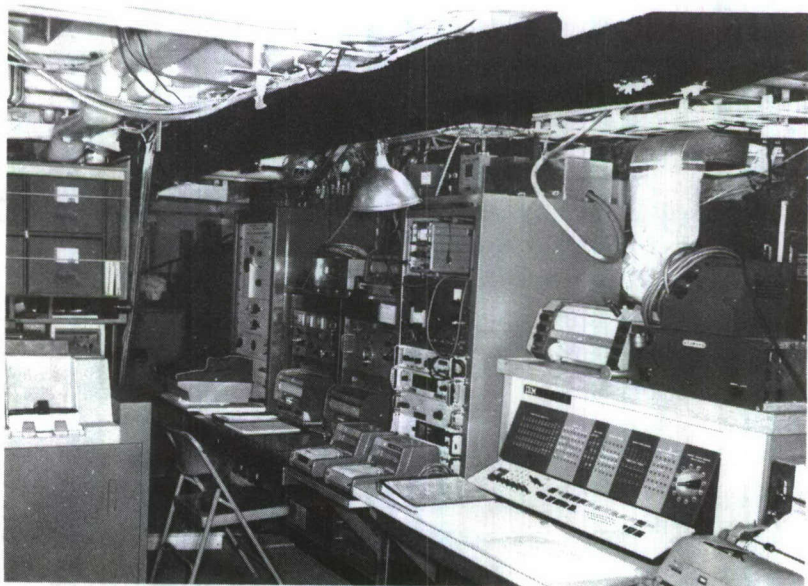


Deflections of the vertical (top graph) and undulations of the geoid (middle graph) along a traverse across the Puerto Rico Trench, with compared values based on astrogeodetic and gravity measurements. Profiles of gravity anomalies and bottom topography are shown in the lower graph.

Another important aspect of the instrumentation development program is the effort to improve the navigation of research ships at sea. One of the most limiting factors in oceanographic research is the reliability of ship positioning. Usually one mile is the expected accuracy in the open sea when cloud cover permits star fixes or where long-range electronic systems are available. Earth satellites increase position accuracy by about an order of magnitude, and in addition provide 24-hour-per-day positioning. This increased accuracy will provide a new dimension to ocean science at sea. The Navy Ocean Science Program is providing this capability to oceanographic research ships engaged in this program.

It is patently obvious that oceanographers do not develop electronic digital computers, but efforts are now being made to

adapt computers for use aboard research ships. The volume of data collected during most oceanographic cruises is so great that high-speed data-handling and reduction techniques must be applied. Present efforts are to record, reduce, and store gravity, magnetic, sound-speed, and navigational data, echo soundings, and other environmental sensor data in shipboard computers, so that a continuous display of scientific results is available to the scientists. This technique offers the investigator the opportunity to evaluate his results and to modify his cruise plans as necessary. It also reduces or eliminates the need for data reduction ashore. At best, a costly delay has been imposed by post-cruise data reduction on making the information available for use. A substantial program of development lies ahead for fuller and effective utilization of modern computers in oceanography.



A digital computer on a research ship. Such computers are in increasingly common use on research ships for the recording and reduction of routine navigation, bathymetric, gravity, and magnetic data. Programs have been written so that the same computer also can be used as a general-purpose computer by scientists on board the ship.

SPECIAL-PURPOSE PLATFORMS

As the state of our knowledge of the oceans progresses beyond a general understanding of the major features and forces, we must make investigations with increasing precision and complexity. Operations from conventional ships and piers do not satisfy requirements. Also, as mathematical models for prediction are developed, we must have the capability to make measurements over long periods at selected sites to determine the validity of the model. We have learned that many observations and tests can be more economically carried out from platforms specifically designed for the purpose. These special-purpose platforms are a unique national resource.

Oceanographic research ships are the work horses for conducting research at sea. In the past they have been conventional ships, in terms of standard hulls and propulsion systems. Recently, the Naval Ship Systems Command, in concert with the oceanographers in the Navy Ocean Science Program, have designed a new ship, now under construction, to meet the requirements of the latest technology of work being incorporated. The new ship possesses the following highly desirable characteristics:

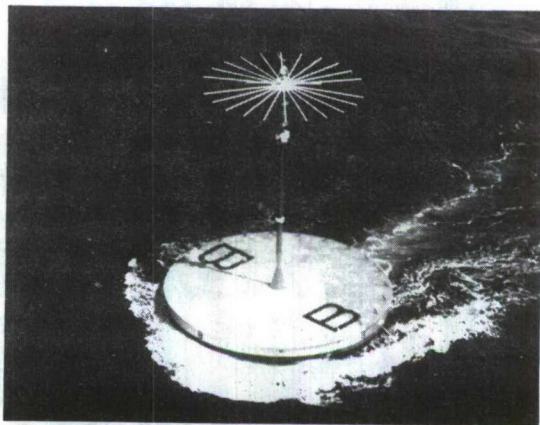
1. Cycloidal propellers, fore and aft, to allow the ship to maintain geographic position in ocean currents of one knot and wind speeds of forty knots, broadside to the ship.
2. Pilot house and bridge located to provide maximum visibility of all scientific areas on deck.
3. An option to perform all foreseeable scientific tasks at sea, by the use of portable systems. Examples are: handling deep research vehicles, drilling for long cores in deep water, towing large objects such as Flip, handling large acoustic arrays through a center well, handling large dredges on a stern ramp, and carrying large parties of students for training purposes. Several such tasks, but not all of them, may be performed during a single cruise. These new ships have been designed to be operated with minimum crew size and minimum maintenance in an effort to check the rising costs of research-ship operations.

OCEAN DATA STATIONS

The requirement to make long-term measurements at selected sites has led to many programs to obtain platforms moored to the ocean floor and supporting instruments at desired locations in the water column.

In support of the needs for synoptic measurements over widespread geographic areas for long time periods, a large effort is underway in the development of oceanographic buoys and their associated sensors. The largest such program is the development of "Monster" buoys. These are moored 40-foot diameter buoys that can measure and record 100 channels of scientific data. Both short-term and long-term memory devices are on the buoys; the short-term memory device is used to telemeter data to shore and the long-term memory device to store collected data for periods up to one year. The "Monster" buoys can be used, for example, as masters in arrays of buoys (moored or floating) that record oceanographic and meteorological data in critical or remote regions. Work is guided by the research scientists from private institutions, industry, and Navy laboratories from the viewpoints of both technology and scientific utilization. This program will supply much of the buoy technology required by the operational Navy for ASW systems involving fixed stations in the deep sea.

The Office of
Naval Research/Convair
Monster Buoy



Another buoy system, Sea Spider, has been developed to provide a stable support system for underwater instruments placed in very deep water. It consists of a submerged float moored by three wires whose buoyancy is adjusted to zero by external floats. An experimental model installed in 2600 feet of water exhibited movements essentially equal to or better than the accuracy of measurement of its position—less than three feet. Design of a system for installation in 17,000 feet of water is currently underway.

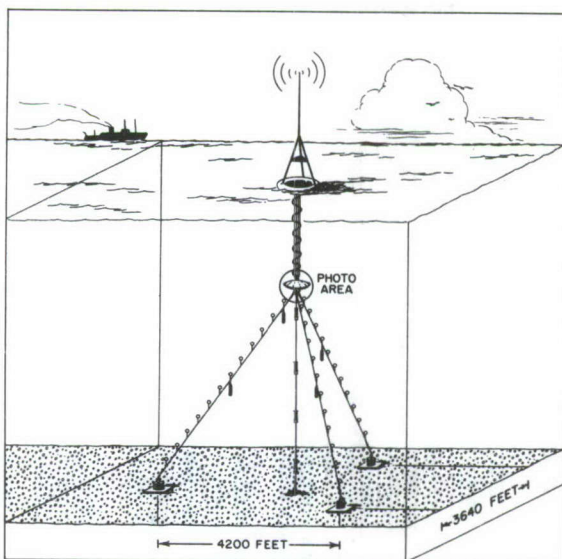
For some types of measurement, a platform is required which will exhibit a very high degree of stability in high sea states. A unique spar buoy, some 350 feet long, was designed and constructed. It moves vertically less than one foot in waves 15 feet high. It can be towed from place to place while lying horizontally on the water and can be erected (flipped) to a maximum draft of 300 feet at will. This technique allows transport at moderate speeds and permits equipment installation at dockside. Accommodations for six to eight men are provided for 30 days at sea.

The need for long-term investigations with fixed equipment has led to the construction and installation of fixed towers in moderate depths of water. Four such towers are actively used in the Navy Ocean Science Program.

Argus Island—A tower atop a 15,000-foot underwater mountain some 30 miles southwest of Bermuda. The mountain top is a flat plateau, about five miles in diameter, 200 feet under the ocean surface. Argus is near the southern edge of the plateau, for ease of installation of sensors on the steep slope of the sea mount. About 30 persons can be accommodated in comfort.

NEL Tower—A platform in 60 feet of water near San Diego, equipped for long-term measurement of physical, chemical, meteorological, and acoustic measurements.

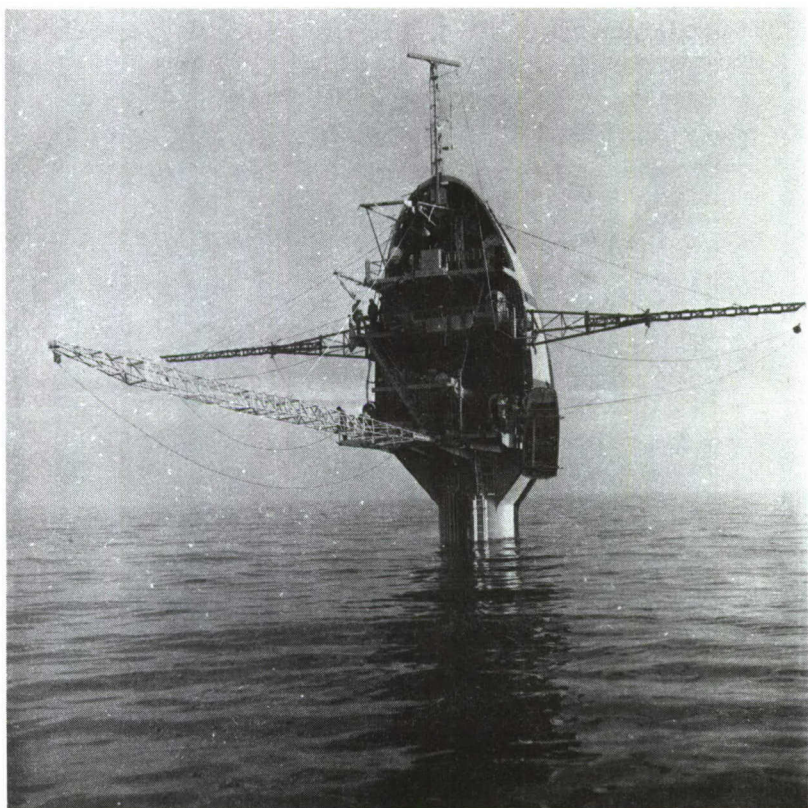
MDL Towers—Two towers, one in 60 feet of water and a very large structure in 100 feet of water near Panama City, Florida. These towers are used in specialized studies of Gulf of Mexico phenomena.



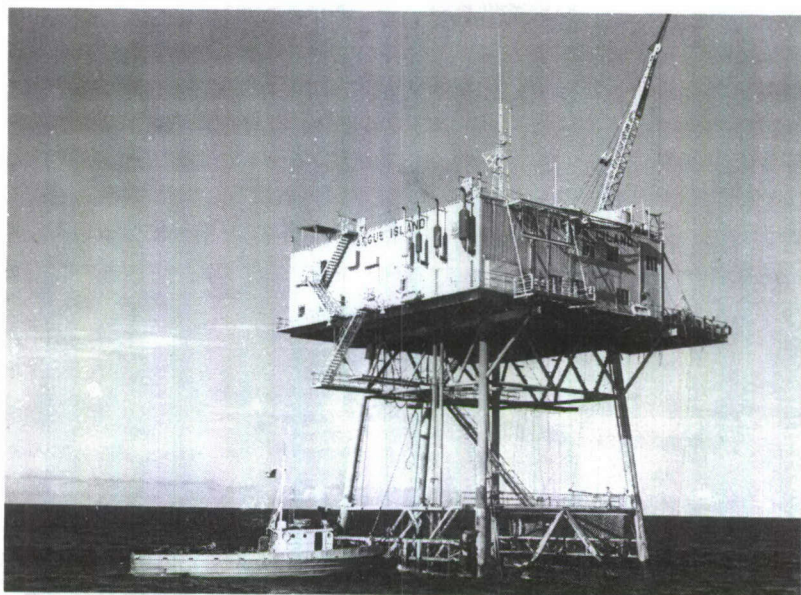
Sea Spider—This experimental model was installed in 2600 feet of water with the subsurface buoy 115 feet below the surface.



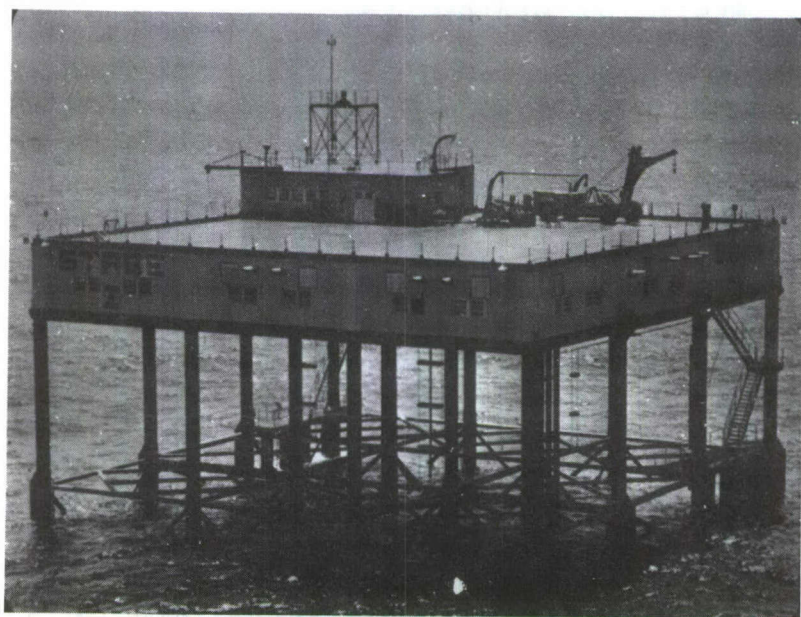
A diver works on the Sea Spider subsurface buoy. Movement of the buoy was less than three feet.



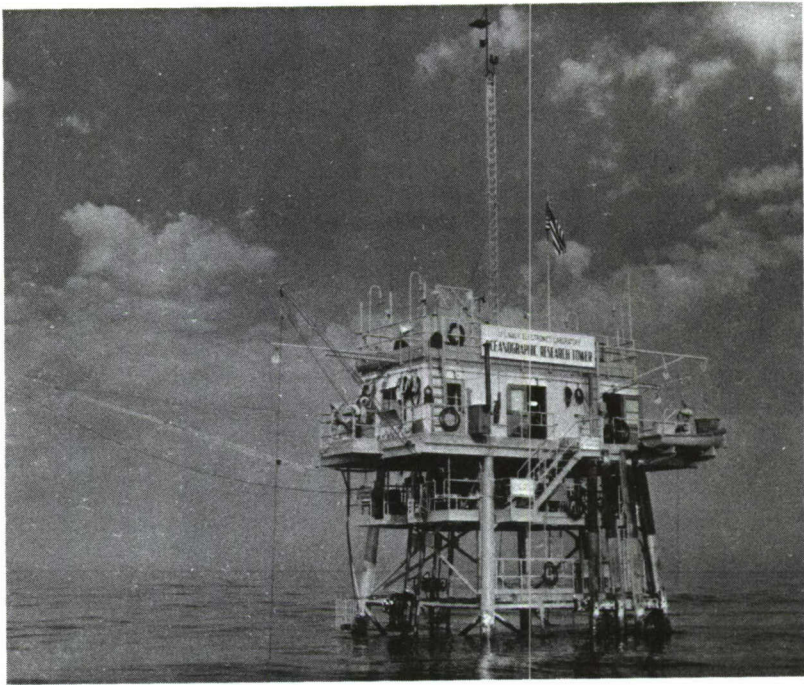
Floating Instrument Platform (FLIP)—In the vertical position shown, its draft is 300 feet.



Argus Island



MDL Tower in 100 feet of water



NEL Tower

MAJOR ACCOMPLISHMENTS

Three recent reports have provided excellent reviews of the achievements that have taken place in the field of oceanography within the last few years.* The Navy Ocean Science Program played a major role in supporting the research from which many of these achievements resulted; therefore, it is not the intent of this report to present a similar detailed review. Rather, only some of the accomplishments which have been of particular significance to the Navy have been selected for discussion.

The accomplishments within the Navy Ocean Science Program fall into two broad categories. One concerns the improvement of our knowledge and understanding of the ocean environment itself. The other involves the improved technology that has resulted which permits man to obtain information more efficiently about the oceans and work either on, within, or over it. The following sections describe accomplishments from both these aspects of the Navy Ocean Science Program.

OCEANIC CIRCULATION

The movements of the waters in the oceans are extremely complex. The accumulation of knowledge about these movements by ocean scientists, particularly during the last decade, has resulted in an overall understanding of oceanic circulation which is a major achievement. The gross circulation patterns in the world oceans have been described, the sources of major water masses identified, and the trajectories deduced and residence time estimated for deep-ocean waters.

The major surface currents have been studied, and their extent, breadth, volume transport, and water velocity have

*These reports are cited in the next section, "Support of Other National Objectives."



A diffusing patch of fluorescent dye is used to study diffusion processes in the surface layers of water bodies. This photograph is of a dye patch 2-1/2 hours after an introduction of 100 kilograms of Rhodamine-B dye about 15 feet below the surface at the head of the plume on the left of the picture. The vessel below the dye patch, which is 100 feet long, gives an indication of relative size of the spreading material. Wind direction is indicated by the trail from the smoke bomb on the extreme left end of the picture.

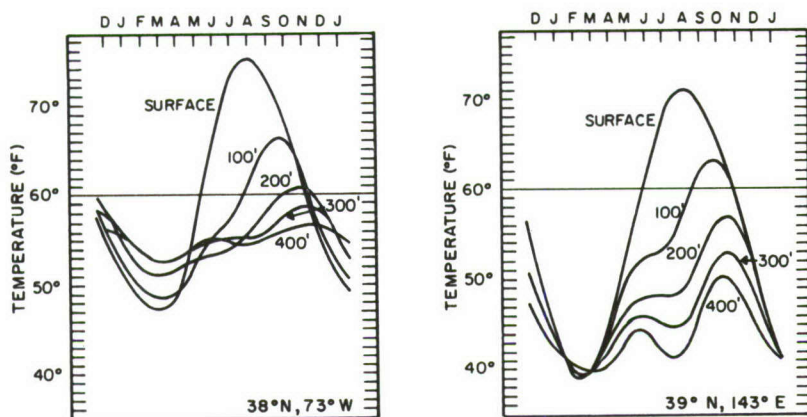
been measured. Much of this effort has been due to the development of associated technology in buoys and sensors; in particular, subsurface currents have been discovered, and several of them have been the subject of major oceanographic expeditions. Other subsurface currents are suspected from theoretical considerations and need to be examined. It is also now known from observations that the deep waters are in constant motion, in many cases with startling velocities that have modified our concepts on the amount of water transport, sedimentation, and erosion in the oceans.

The theory of ocean circulation has advanced to the point where, in most cases, experimental verification is now necessary for further advancement. In terms of the ultimate understanding of the processes which take place in the ocean, our present knowledge is a bare beginning; but in terms of what was known before World War II, this knowledge is significant.

THERMAL STRUCTURE

Above the permanent thermocline, the temperature of the ocean water is the controlling environmental factor influencing the transmission of sound and the effectiveness of Navy sonar systems. This layer of the ocean is also a major source of heat for the atmosphere and, as such, influences the weather and, in turn, most naval operations.

Since World War II, with the advent of the bathythermograph, millions of measurements of the thermal structure of the upper layers of the oceans have been recorded. Many of these have been obtained from research ships in the course of their studies throughout the world oceans. Others have been collected by naval forces for operational purposes. A large fraction of these recordings have been analyzed and the results presented in a form which is having a significant impact on naval operations. Bathythermograph observations from the North Atlantic, North Pacific, and Indian Oceans as well as the Mediterranean are being digitized and, by use of high-speed computers, processed to give a comprehensive picture of temperature structure in the top 400 feet.



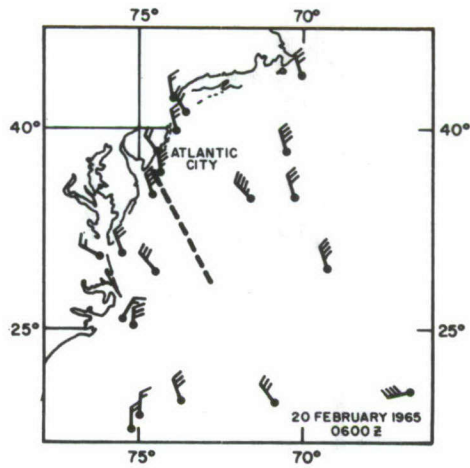
Annual temperature cycles in the upper surface layers of the North Atlantic (left) and North Pacific (right)

Temperatures at selected depths are presented on a month-by-month basis on a closely spaced grid over the entire extent of each ocean. The data are subjected to two-dimensional space interpolation, space smoothing, and time smoothing by Fourier approximation. The results of this work have been used extensively in the development of operational Navy environmental prediction systems.

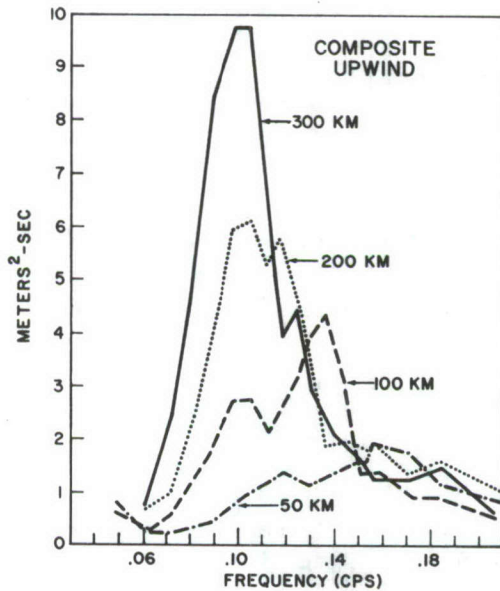
WAVE FORECASTING

The Navy presently provides its forces with wave forecasts on a daily basis and minimum time tracks for transits of the North Atlantic and North Pacific Oceans by Navy ships. The ability to provide these forecasts is largely the result of a long-term research effort aimed at better understanding wind-generated waves from their generation stage to final decay.

Several theories of wave generation by the wind have been proposed, and wave-growth models based upon them as well as empirical data have been developed. Models of the spectra of waves also have been made and continually improved to provide the means for statistically describing the sea surface. The measurement of waves from ships and towers has provided the data for developing such spectra. The aircraft, with its recently



Observed wind conditions and the flight path of an oceanographic aircraft fitted with wave-profiling radar



Schematic diagram of the energy spectra computed for fetches of 50, 100, 200, and 300 kilometers. This experiment has provided a clear insight into the effect of fetch on the rate of wave growth.

PHYSIOGRAPHY

In the past 20 years, precise echo sounders have been developed and used in all major ocean areas to provide data so extensive that all of the major topographic features of the sea floor are known and charted. The ocean-science contribution to this effort has been the development of precise echo sounders, the recording of a significant fraction of the data at sea, and the geological interpretation of the soundings in the form of physiographic diagrams. The physiographic diagrams are used in all forms of oceanographic investigations and truly provide a new dimension to oceanography. Because the sea includes such extensive areas, these charts and diagrams are as yet inadequate in detail. Many more measurements are required, as well as improvements in instrumentation, before the physiography of the ocean bottom is known adequately for Navy purposes.

The charts and diagrams are most valuable in submarine activities and underwater sound propagation. Particularly, the roughness and slope of the bottom topography affect sound transmission. Best transmission conditions occur in the flat abyssal plains. Hence, a significant accomplishment has been the determination that abyssal plains are flat and that they are extensive.

Slopes on continental rises (seaward side of the continental slope) have been found to be quite small. These factors are of importance in ASW. A knowledge of the irregular topography in mountainous areas, which is still very inadequate, and the shape of the continental slope, play important roles in submarine operations, sound propagation, salvage operations, and building engineering structures.

SEDIMENT AND CRUSTAL STRUCTURE

Marine geophysical programs supported by the Navy for the last two decades have produced a revolution in geophysics, while also providing a firm base for understanding and developing sonar and many aspects of deep-sea technology. These programs



Physiographic diagram of the Indian Ocean, based largely on soundings made during the International Indian Ocean Expedition

include long-range underwater sound transmission, the gravitational and magnetic fields of the earth, and emergency solutions to problems of salvage and installation of deep-sea engineering structures. A sufficiently large number of geophysical measurements have now been made to allow typical characteristics of the mantle, crust, and sediments in the oceans to be fairly well known. In fact, these broader structures are as well or better known at sea, as a result of these investigations, than they are on land.

In the most common type of oceanic province, the abyssal plain, the sediments beneath the ocean floor have been found to be flat and undisturbed and about one to three kilometers in thickness. They are commonly underlain by a layer of high surface relief having an intermediate seismic velocity. In other cases they are supported directly by main crustal rock about five kilometers thick. The base of the crust, the Mohorovicic discontinuity, is about ten kilometers below sea level beneath these plains. The lower crustal material has about the same seismic velocity as it does on continents, and is usually considered to have the same composition in both types of crusts. The mantle beneath the crust also appears to have about the same composition in oceanic and continental regions, since seismic velocities in both regions have the same average values.

In oceanic ridges and over sea mounts the sediments are usually thin or absent, except in sharp, narrow valleys. Ocean ridges are also characterized by a relatively thin oceanic crust underlain by a mantle layer having a relatively low seismic velocity and low density. Magnetic anomalies over the ridges show characteristic variations, believed by some to be a result of sea-floor spreading. Heat-flow rates are high over the ridges (seismicity is also usually higher than in abyssal plains).

Similar characteristic features have been determined for other types of provinces. In oceanic trenches, where water depths are between five and ten kilometers, sediments vary greatly in thickness, as do the depths to mantle rocks. A large negative gravity anomaly exists over the typical trench, indicating either a relative mass deficiency in the mantle, or a great thickness of

low-density material in the crust. Many island areas, particularly the Hawaiian Island archipelago, contain large mass excesses. In the Hawaiian area this mass may have resulted from the outpourings of lava flows that occurred so rapidly that the crust and mantle have not readjusted (by rock creep and flow) completely to this excess of material.

GRAVITY AND GEODESY

Means have been developed for measuring the earth's gravity field in oceanic areas. Extensive gravity measurements have been obtained from the Navy Ocean Science Program, the oceanographic operations program, and in the operations of other agencies. The measurements have provided valuable data over many ocean areas, and particularly over selected regions. Many times more data, and also more accurate data, are required, however, before the Navy's needs in navigation can be satisfied.

The sea gravity measurements that have been obtained have had considerable impact on the development of a world geodetic system, on the calculation of local deflections of the vertical (deviations of the vertical to the earth's reference due to local mass anomalies), and on providing the data required to improve our knowledge on the shape of the earth's geoid (approximate sea-level surface). These factors all have had application to improving navigational control at sea. Attempts are now being made to use the calculated gravity anomalies at sea to improve the predicted orbital paths of satellites and, hence, to improve the accuracy of the navigational satellite system developed by the Navy. The gravity anomalies also have had wide application to interpreting crustal and subcrustal structures in the ocean areas.

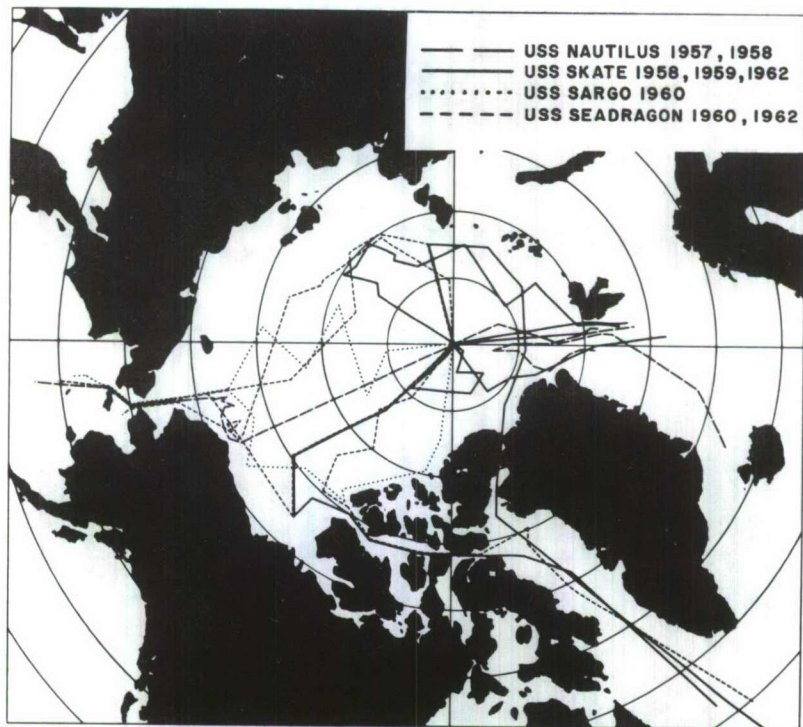
ARCTIC

The Navy has successfully occupied the polar ice islands, operated aircraft and navigated ships and submarines in arctic waters, developing by these means both extensive and detailed

knowledge of the arctic environment. For its operations, the Navy must have information of the ice, bathymetry, weather, communications, human survival, and similar factors in arctic regions.

Various under-ice submarine operations have made important contributions to our knowledge of the physics of sea ice, on the forces required to break through the ice, and on the acquisition of ocean data. From submarines much of the available bathymetric data on the Arctic Ocean has been obtained.

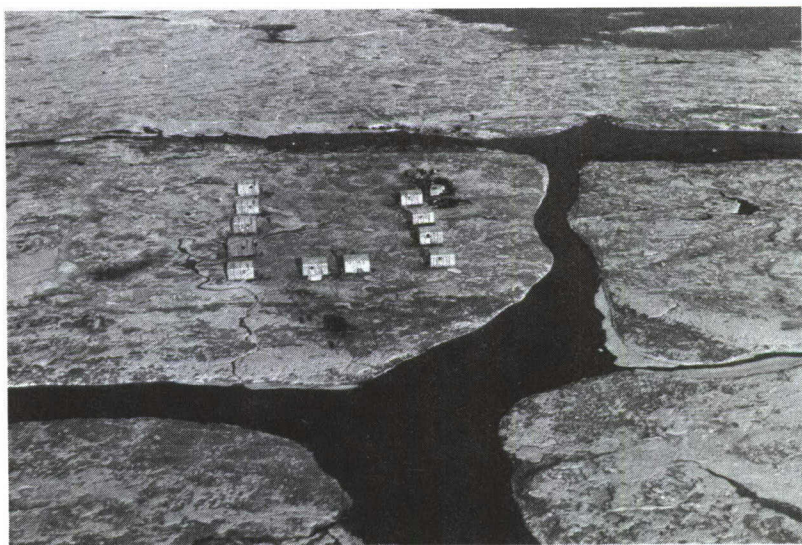
The Arctic Research Laboratory at Barrow, Alaska operates numerous field stations, including the research stations on ice islands. Temporary stations were located on ice flows Arlis I, Arlis III, and Arlis IV. A permanent station existed for four years on ice island Arlis II, which drifted approximately 5000



Under-ice cruises of USS NAUTILUS, USS SKATE,
USS SARGO, and USS SEADRAGON

miles from near Barrow through the Arctic Ocean, almost past the North Pole, and through the Greenland Sea to near Iceland, where it was evacuated. A permanent station is now located on Fletcher's Ice Island (T-3). Research on these ice stations has included programs in gravity, magnetics, underwater acoustics, seismology, micro-meteorology, physical and chemical oceanography, sediment coring and heat-flow measurements, ice physics, and ice drift. These programs have been supplemented by airborne studies of the distribution and dynamics of pack ice.

Achievements from the ice-station and airborne studies include interpretations of arctic basin geology and crustal structure, and considerably more precise knowledge of factors that affect ice conditions, particularly the rates of ice formation, dissipation, deformation, and drift. The arctic investigations have produced practical applications; these include improved survival techniques, aircraft landings on ice, use of ice for camp construction, over-ice vehicular movements, ice breaking, ice forecasting (long and short period), ice penetration by submarines, and bathymetric maps of the major physiographic features in the Arctic Ocean.



Arlis II in July 1961, two months after the establishment of the ice-island research station

GEOPHYSICAL INSTRUMENTS AND SYSTEMS

Among the many instruments that have been developed in the course of research programs, the geophysical instruments for making measurements of elastic waves, magnetic fields, and gravity fields have made outstanding contributions to the survey and operational needs of the Navy. They also have enabled progress to be made on a very wide front of geophysical investigations.

Several significant geophysical instruments have been made available for use in Navy programs, particularly survey programs. The early development in 1953 of precise echo sounders, and subsequent programs for their improvement, were supported by the Navy Ocean Science Program, as were the following other instruments: sub-bottom echo sounders to determine the fine structure of the upper layers of sediments; seismic-reflection profilers to provide data on the thickness and grosser structures of the sediment layers; seismic-refraction systems to furnish data on the thickness and elastic-wave velocities of the crustal and subcrustal layers; gravity meters, operated near the center of least motion on surface ships and on submarines, to provide data on variations in geological structures and bottom topography; and magnetometers to provide measurements of the total earth's field and of differences in the field.

OCEANOGRAPHIC BUOYS

The increased state of buoy technology that has developed over the past several years has been a major accomplishment of the Navy Ocean Science Program. This technology is necessary for the development of oceanographic buoy systems for environmental data collection in open ocean areas, particularly to meet the needs of Navy environmental prediction systems. It includes not only an improved understanding of the influencing factors upon buoys, but also the hardware and deployment techniques to be used in operational networks.

The development of both drifting and moored buoys for recording oceanographic data progressed slowly during the 1950's

but has been more rapid since then. Buoys have been used in ocean-science research mainly for the measurement of ocean currents, but the long-recognized need for expanding their capability to include measurements of temperature, pressure, salinity as well has led to the development of appropriate sensors.

Oceanographic and meteorological sensors for long-term unattended operations in the ocean are a reality. Efforts continue in evaluating them, in improving their performance, and in developing new sensors for parameters which cannot now be measured from buoys at sea.

International recognition of the need for oceanographic-meteorological buoys in the oceans has taken the form of agreements on marking and maritime safety equipment. In addition, a concentrated effort is under way, on an international scale, to obtain exclusive radio frequencies for use in telemetering the data from these platforms.

Much work has been done on the long-range telemetering of the data. Hardware has been developed for a data-acquisition package for use in buoys, on radio transmitters and receivers to meet the rigid international frequency requirements, on communication systems for interrogating the buoys from shore, and on the electrical power supplies necessary for long-term unattended operation.

The state of the art has now reached the point where truly significant scientific experiments may be mounted using this powerful tool. Networks for operational reporting of environmental data from all the world oceans on a routine basis may now be conceived. In the overall view, this accomplishment is significant from the viewpoint of the Navy and the country as a whole.

DEEP UNDERWATER VEHICLES

In 1957, the U.S. Navy bought the Italian bathyscaphe TRIESTE and in 1958 brought it to this country. This start has been of major significance to the U.S. achievement of its position of leadership in exploring the ocean depths. An over-

whelming portion of the world's deep-sea vehicles have been or are being built in this country.

These vehicles range from the small one- to two-man submarines for exploration of the continental shelves to vehicles capable of routine operations at 15,000 feet. Units capable of searching the ocean floor at 20,000 feet are coming soon.

A major step in this evolution was ALVIN, a vehicle built under the ocean-science program to conduct research to a depth of 6000 feet. A part of its research was directed toward determining the best methods of utilizing deep vehicles to explore the oceans. Its success in opening this area of the world to man is amply demonstrated by the fact that, to date, priority requirements for recovery of material vital to this nation (the unarmed atomic weapon near Palomares, Spain) and the inspection of installations in the Atlantic Undersea Test and Evaluation Center (AUTECH) and other areas have deferred the accomplishment of many research missions. ALVIN will soon be joined by about six other vehicles of similar capability, and it is hoped that the ALVIN will be able to resume its intended primary mission.

MAN-IN-THE-SEA PROGRAM

The continental shelf areas of the world, which lie within depths of less than 600 feet, constitute about five percent of the earth's surface area. While a limited capability for diving in these shelf areas has existed for several decades, the hazards involved and the limited time which could be spent doing useful work has precluded widespread use of the techniques. The pioneering ideas and work of Captain George Bond on the development of saturation diving techniques, in which the human body is allowed to reach gas saturation equilibrium at the depth at which work is required, are currently being explored and exploited.

An at-sea experiment, Sealab I, was conducted in 1964 to confirm prior laboratory work, and to make observations and preliminary measurements of human ability to adapt, both physiologically and psychologically, to the environment at

193 feet, and ability to perform useful work. Four men lived for eleven days on the ocean floor, performed assigned tasks, and were successfully brought to the surface. No ill effects were encountered.

In 1965, a much more complex experiment was conducted in 205 feet of water near La Jolla, California. Here three teams of ten men each lived on the ocean floor for two weeks per team. A comprehensive program of physiological and psychological measurements was carried out. Ocean-floor experiments in physical oceanography, biology, salvage, and mining were performed, and provided a mechanism for human-performance measurements.

These experiments were outstandingly successful, and have provided a basis for continued work, both in research and engineering, to make saturation diving an everyday work tool for Navy and commercial divers. They have engendered more than a dozen saturation-diving systems in the United States, most of which are currently being commercially employed.

SUPPORT OF OTHER NATIONAL OBJECTIVES

The mission of the Navy Ocean Science Program is to support national defense. The need for ocean-science programs to support other national objectives has been aptly described in several reports, the most recent of which are the following.

1. "Effective Use of the Sea," Report of the Panel on Oceanography of the President's Science Advisory Committee, June 1966
2. "Oceanography 1966, Achievements and Opportunities," Publication 1492, National Academy of Sciences, National Research Council, 1967
3. "Marine Science Affairs—A Year of Transition," National Council on Marine Resources and Engineering Development, Feb. 1967

A vast store of environmental information and, in many areas, a unique capability for operations at sea and interpretation of data, has been developed in the course of pursuing the Navy Ocean Science Program. The Navy is fully aware of the importance to the general welfare of the opportunities for increased exploitation of the seas for purposes other than defense. It is further aware of its responsibilities for contributing to those goals by sharing its knowledge and experience with industry, educational institutions, and other agencies of the government who have specific mission responsibilities for various goals related to the well-being of the nation. The high cost of research at sea and the present limited number of trained scientists relative to the total national interest make it mandatory that programs be carefully planned and coordinated with a view to the total spectrum of national interest.

Some of the national objectives discussed in the previous publications to which the Navy Ocean Science Program makes a direct and major contribution, in the course of its normal defense-oriented support programs, are discussed in the following portions of this section.

MARINE FOOD RESOURCES

The requirements for environmental information needed in exploiting the oceans for food parallel in many respects the requirements of the Navy for support of its activities, primarily that of undersea warfare.

Knowledge of the temperature and salinity structure of the surface layers of the ocean is an important tool in predicting the abundance and availability of commercial fish and the abundance, distribution, and migration of game fish. The Navy studies of ocean temperature and salinity distributions and heat budgets, and the development of environmental prediction may well be applied to fishing operations to increase yields.

The deep scattering layers of the ocean are comprised of marine animals which range in depth from the surface to about 1000 meters. The study of these scattering layers, of interest to the Navy, yields important information on the ecology of marine life, including the role of plankton in the food chain. Navy efforts to identify the acoustic sounds of biological origin in the oceans contribute to the understanding of marine ecology and to the localization of fish schools and species.

Large-scale cooperative investigations, such as the International Cooperative Investigation of the Tropical Atlantic, and the current investigation of the Eastern Tropical Pacific, have been spearheaded on the part of the United States by the Bureau of Commercial Fisheries and are strongly supported through the resources of the Navy Ocean Science Program. Such studies have provided descriptions of large regions of the world oceans and have contributed knowledge of the dynamics and physical and chemical processes taking place within them. For fisheries development, these studies have provided environmental data for correlation with fish abundance and distribution. For the Navy they have provided environmental knowledge needed to support a variety of naval operations.

TRANSPORTATION

The Merchant Marine has many areas of interest in the ocean sciences in common with the Navy. The design of ships and their

effective operation depend on a knowledge of the seas, particularly the motions and forces at or near the surface.

The Navy sponsors a program of research on ocean-wave mechanics and the prediction of sea states. The results of efforts to date have produced the forecasting capability now used to provide routinely least-time tracks for the Military Sea Transportation Service. Such forecasts could assist the Merchant Marine as well.

The Navy's detailed investigation of ocean-current systems, particularly in the North Atlantic Ocean, should aid all mariners. A towed thermistor technique used initially by scientists in the Navy's program to track the meandering of the Gulf Stream, is being used by merchant ships to reduce passage times, in a modern version of the contribution Benjamin Franklin made to the Merchant Marine by issuing charts of the Gulf Stream.

MINERAL AND ENERGY RESOURCES

A significant part of the Navy Ocean Science Program concerns itself with the ocean floor. Techniques and programs have been developed for precision depth measurement, and measurement of roughness, slopes, sediment, and rock below the sea floor. Programs are also concerned with the collection and analysis of cores, and the rapid and accurate measurement of bottom magnetic and gravimetric properties. While this knowledge is essential for certain Navy developments, these techniques and the information derived from them are precisely those needed for subsurface mineral-resources location. Industry has already adopted some of the Navy technology developed for this purpose.

In the exploitation of mineral resources, industry has access to the information developed by the Navy Ocean Science Program on such items as currents, bottom characteristics, underwater sensors, underwater manipulators, underwater photography, underwater vehicles, underwater structure technology, wave-forecasting techniques, and advanced diving techniques. In turn,

the Navy also profits by contributions of industry to such technology.

WEATHER PREDICTION

The importance of the role of the oceans in the global weather picture is well recognized. The Navy Ocean Science Program supports studies of atmospheric weather and its prediction through consideration of air-sea interaction, measurements of surface temperature, studies of heat budget, studies of ocean currents, and the development of sensors which telemeter relevant oceanographic and meteorological information from buoys anchored at remote locations.

Another type of "weather" lies within the ocean itself, characterized by ocean currents and temperature distribution. This "weather" affects ship operations, diving and salvage operations, resource exploitations, underwater habitation, erosion, underwater communications, marine pollution, biological activity and abundance, and atmospheric weather. The investigation of this type of "weather," which affects military and civilian interests alike, represents a major emphasis of the Navy Ocean Science Program.

PUBLIC HEALTH AND RECREATION

The programs in the Navy Ocean Science Program concerning near-shore currents and the effects of these currents and wave action are also of interest to the preservation of recreational beach areas and the understanding of mechanism of the sea in carrying off sewage effluents. A relatively modest program of marine chemistry provides useful information on contaminants, such as lead, in the sea and the effects of such pollution on marine life, including game fish and commercial fish. Studies of the habits of sharks can lead to better protection of beach recreational areas as well as to the safety of military and civilian personnel working or attempting to survive in shark-infested waters. The programs which support sea-surface predictions will contribute to the safety of small recreational craft.

ENGINEERING

The first essential in studying or exploiting the oceans for any purpose is to possess the necessary tools. In the oceans this is a formidable requirement indeed. The Navy Ocean Science Program, in supporting what is essentially a pioneering effort in environmental research, has had to invest a large fraction of its resources in the development of measuring devices such as current meters, special navigation devices, and instruments to measure salinity, temperature, pressure, depth, wave height, turbidity, magnetic properties, and gravity. Special research platforms such as Flip and DRV's have been developed and tested. Devices for coring, communication, biological sampling, handling of cables, seismic sub-bottom profiling, and computerized real-time data processing have been developed and are constantly being improved. Studies of marine fouling and corrosion prevention and investigations into building and maintaining underwater structures and habitats are part of this program. The instruments, techniques, and know-how are of inestimable value for exploitation of the sea for any purpose whatever—Navy, industrial, or general welfare.

INTERNATIONAL UNDERSTANDING AND COOPERATION

The oceanographic community, in common with the scientific community in general, has provided a good example of the possibilities for, and the potential for beneficial results from international cooperation. The Navy Ocean Science Program is fully cooperating in this activity by participating in information-exchange programs, and sponsoring international symposia in oceanography in such fields as ocean wave spectra, fluid dynamics, and marine biology. Direct support is being given to research projects in European, South American, and African countries; support is also offered through our contracts, by the exchange of studies and professors with other countries, and by participation in the planning and carrying out of cooperative

international geophysical and oceanographic expeditions. Examples of these are the International Indian Ocean Expedition, International Cooperative Investigations in the Tropical Atlantic, and the Cooperative Studies of the Kuroshio.

EDUCATION

After World War II, the Navy Ocean Science Program became the principal source of support for the major university and private oceanographic research institutions. Later the National Science Foundation shared this support. This period since World War II has seen a remarkable growth not only in the size of the institutions but also in the establishment of many new ones. This growth has been aggressively supported through contracts by the Navy Ocean Science Program, as a means of training scientists to meet the needs of the Navy and to provide the manpower resources necessary to perform research in the national interest. The increasing numbers of graduate students now being trained is a direct consequence of the deliberate policy of the Navy to encourage education through the support of research projects and the provision of facilities in this field.

PROSPECTS FOR THE FUTURE

Oceanography is a field of activity in which the Navy, probably more than any other agency of the Federal Government, will continue to be active. The Navy has the responsibility to look well ahead and prepare for future needs, to examine critically the scientific feasibility of technical solutions, and to insure that the scientific base is adequately developed for coupling with naval operations.

The scientific base derived almost wholly from the combination of naval in-house laboratory and contract research programs, will continue to develop mainly from this source. The choice of broad fields of inquiry will be made with the view towards providing options to naval planners in dealing with future needs.

The responsibility of the Navy Ocean Science Program in exploratory or advanced development, is largely to examine the scientific feasibility of new concepts, to provide a continuing interaction with parallel but dominantly engineering or operations programs, and to identify and fill gaps in scientific knowledge needed for developing new systems. This concept of service by the Navy Ocean Science Program is firmly rooted in the traditional willingness of individual scientists to assist the Navy as consultants. This tradition, always a strong force in research and development, will be recognized and encouraged in future programs.

The Navy of the future will be shaped by the developing understanding of the environment in which it operates, just as today's Navy has been shaped by basic oceanographic knowledge not available a few years or a few decades ago. It is critical to naval development that ocean science should progress rapidly and comprehensively.

Within the scientific program, emphasis will change from year to year as our realization of potential applicability grows. In the immediate future, stress will be placed on the following areas.

OCEAN DYNAMICS

From the scientific point of view, the ocean is an exceedingly complex system. Sophisticated hydrodynamic theory, aided by our newly acquired ability to handle nonlinear equations using computer techniques, has produced a series of mathematical models proposing to reduce the complex motions to order. Theoretical development is currently limited by the unavailability of experimental results to test theories, and to evaluate key parameters that influence the mathematical models. First-order experiments, in the last two or three years, have gathered preliminary evidence on the nature of some dominant modes of motion, and have pointed clearly to logical methods for attacking the larger problem. We have gained reasonable assurance that instrumental techniques can be evolved to bring observation and theory into fruitful interplay and make a substantial improvement in our understanding. Thus, we have an obvious point of departure for a major scientific effort.

The pattern of research into circulation and internal-wave problems on the one hand, and underwater sound transmission on the other, suggests increasing interactions among these programs. It is difficult to conjecture the exact form this interaction may take, but the periods of some sound-transmission fluctuations correspond to periods of internal waves to be expected in the same area. Even rather subtle features of the water structure have long been known to affect sound measurably, and the doppler shifts to be expected in sound transmitted through currents, if properly observed, might provide useful information about the currents themselves. The beginnings of such cooperative investigations are underway or in prospect.

AIR-SEA INTERACTION

The exchange of energy and material across the air-sea interface embraces a large variety of studies. One part of these studies is concerned with the prediction of the growth and decay of wind waves. This aspect has progressed well in recent years,

and a rather refined forecasting technique is available. Vigorous research programs studying the fundamentals of the energy exchange and interactions are aimed at removing some of the remaining empiricism. On the other hand, the exchange of thermal energy is poorly understood. Little advance has been made, mainly because the refined observations required to present the basis for better theoretical models have not been available. It is in the exchange of thermal energy that answers to many problems lie. Included among such problems are the alteration of thermal structure in the upper layers of the ocean, the generation of ocean weather, the maintenance of the global atmospheric circulation, and the propagation of perturbations in climate. Proper instrumentation is being developed slowly and could be greatly accelerated, thus allowing a renewed assault on these problems. The exchange of materials, such as atmospheric gases, across the interface is also very poorly understood. It is clear, for example, that the simple model of continuous equilibration across the interface is not valid. The Navy has a clear concern with air-sea interactions, since they bear on proper understanding of the environment in and near the surface of the ocean, where major defense activities are concentrated.

CHEMISTRY OF THE OCEAN

The complexity of the ocean as a chemical system makes it difficult to find solutions to a number of important practical problems. The electrolytic corrosion of materials in seawater, and their susceptibility to biological attack by marine organisms, are intimately related to the nature of their chemical environment. The transmission of acoustic energy through seawater varies in a complex manner which is dependent, among other things, on the chemical composition of seawater. The chemical nutrients found in the sea determine the extent of biological productivity, upon which rests man's hope of obtaining an increased amount of food from the oceans. The mutual exchange of energy and materials between ocean and atmosphere at the air-sea interface, which is so important in determining our

weather, is dependent to a significant degree upon the surface chemistry of the topmost layer of the water. We are just now beginning to appreciate the possible importance of diffusion processes near the deep ocean bottom; in some cases these may be studied by natural tracer methods, such as the upward diffusion of radium from the sediments into the bottom water. Mixing mechanisms and rates between the upper, intermediate, and deep layers of the ocean can be studied by natural chemical tracers and by the artificially radioactive tracers being continually delivered to the ocean surface in the form of world-wide fall-out from nuclear test explosions.

Navy support of chemical oceanography in the past has been relatively small. The importance of this field, however, both to the Navy and to the nation as a whole, requires that its support be broadened and increased. In determining the scope of such support, it is important to recognize that the problems of marine chemistry are, in a real sense, merely a part of the overall problem of the geochemistry of the entire earth. Thus, man's pollution of the coastal waters and of the atmosphere must inevitably produce corresponding changes in the chemistry of the world ocean. Support of research in chemical oceanography should not, therefore, be restricted merely to considerations of seawater as a complex chemical solution, although this is certainly one of the more important areas of interest. Since the aim of Naval research in oceanography is to understand the medium in which the Navy must operate, marine chemistry must be recognized as an integral component of the mix of inter-related disciplines which comprise the ocean sciences, and receive a corresponding measure of support.

BENTHIC BOUNDARY STUDIES

Underwater cameras and television, heat probes, and the early dives by deep submersibles have each provided special beginnings of information about the waters immediately above the ocean floor, or benthic boundary. As the use of manned vehicles near the bottom in great ocean depths increases, the nature of the benthic boundary layer will determine their limitations.

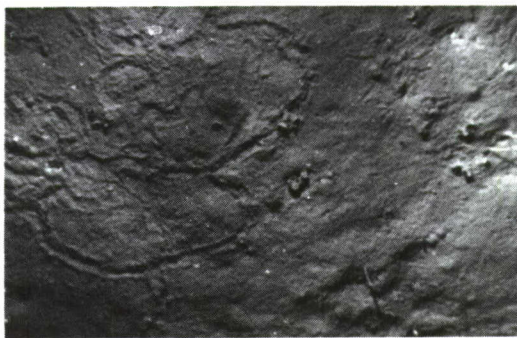
At great depths thermal gradients in the water occur, suggesting instability in the density field. Heat flow from the earth's interior is suspected as the cause of these gradients, but why they are not continuously dissipated by convection is obscure. Indeed, the presence of a layer of suspended material has been detected widely which may make the waters stable. In addition to the questions about thermal structure, those few observations of movement near the bottom now available indicate that the bottom waters are far from being at rest; in fact, evidence of the result of currents is found in many bottom photographs.

The ecology of animals dwelling just above, on, or just below the boundary layer is a field of study of the deep sea into which man has had little more than glimpses. With the undersea research vehicles now available this field should advance strongly.

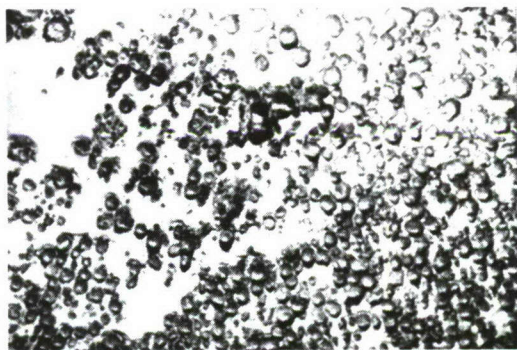
SEA FLOOR TOPOGRAPHY AND SEDIMENT STUDIES

The importance of the shape of the sea floor to the Navy scarcely needs to be stressed again. Its study is a developing art which has long been on the plateau created by the nearly simultaneous invention of the sonic echo sounder and the graphic recorder about 48 years ago. Improvements in accuracy and resolution of vertical soundings, and even the exciting side-looking sonar, all represent little steps beyond the original invention. Means are greatly needed to increase the speed and resolution of bathymetric surveying. These developments will require a considerable parallel program of research accompanying them if they are to be both successful and useful as soon as possible.

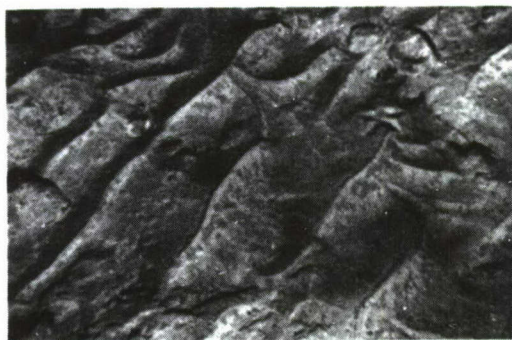
Continued physiographic research into the relationship among topography, process, and structure is important to both sonar and deep-sea technology. It will be continued using the best available instruments—acoustic, photographic, and other. The pressures created by unanswered scientific questions may well provide the impetus and insight for the needed inventions discussed above.



a. Tranquil bottom with no current

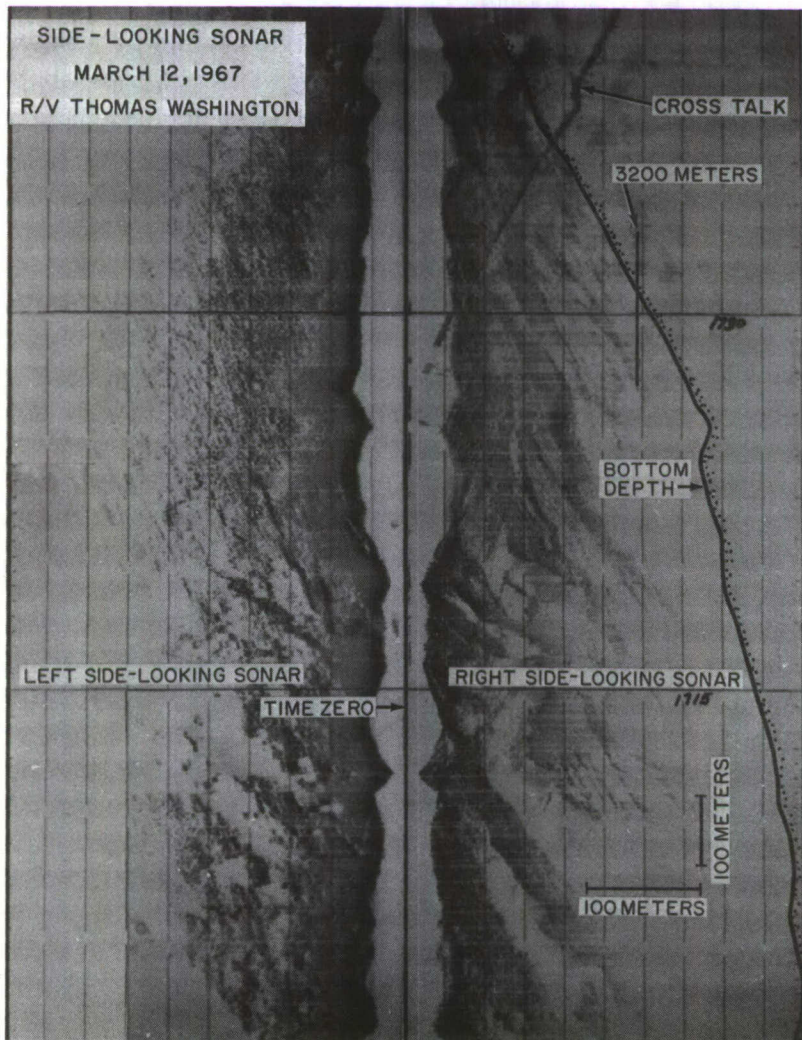


b. Heavy current scouring



c. Well-defined ripples, indicating high current

The influence of bottom currents is evident
from photographs of the ocean floor.

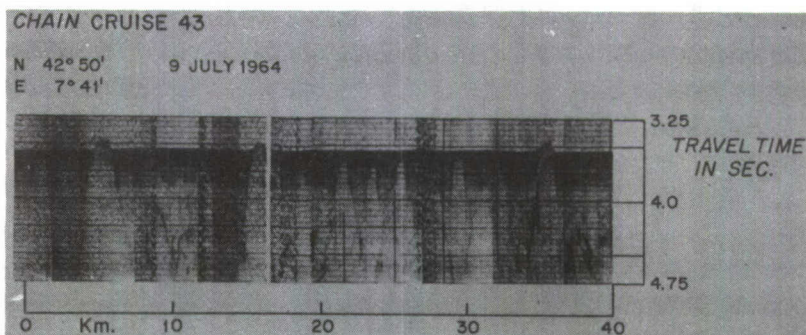


Side-looking sonar record obtained near the sea floor by towing two narrow-beam echo-ranging systems directed horizontally to the left and right of the towed vehicle. Echoes are recorded from rocks, sand ripples, hummocks, and artifacts lying on the ocean bottom.

Studies of sediment in future programs should be directed toward mechanical properties, both those influencing acoustics and those determining the bearing strength and stability of the sediment, as well as the familiar mineralogical and paleontological pursuits. The process of compaction, imperfectly described, can be studied and understood best in deep-sea sediments. These studies should be paralleled by consideration of bottom currents and sediment transport. Chemical and biological processes that influence the gradual formation of sedimentary rock bear on the same questions as mechanical compaction and should be studied as part of this broad program. Some of the special topics concerned with sediments are sketched below, not as an exhaustive discussion but as an indication of emphasis.

The study of gross structure and properties of all oceanic sediments seriously began with the wide use of seismic-reflection profilers. These instruments have far more potential than has been realized in any current sustained program. The development of this line of investigation will be encouraged because of its high relevance to Navy sonar problems and because it is a powerful tool for the study of the oceans. Useful hypotheses of the past five years which depend on the measurement of sedimentary structures deep below the ocean floor have concerned not only the structures themselves but also the deep circulation of the ocean. These hypotheses come from mere description of the structures. The resolution of the method is being improved, and the depth of penetration increased. It has been possible to make promising correlations between the energetics of the reflections and the geologic characteristics of the sediments. This last line of inquiry, of obvious importance to sonar, will be encouraged.

In enclosed basins and other areas where fine, porous clays dominate in the sediment, the sound velocity of the bulk is less than that of the interstitial water because of the mass loading of the sediment. In the subsequent development of the deposit the clays are compacted by the overlying sediments. Thus the sound velocity increases with depth. This process, long known, has received little attention in the deep sea until very recently. Its acoustic effects are neither widely nor completely understood,



A seismic reflection profile across an abyssal plain in the western Mediterranean Sea shows a large number of apparent diapiric structures. They are known to be non-magnetic and they may be salt domes. Deep-drilling programs can be valuable in the further study of the features.

and it is obviously an important field to deep-sea technology, particularly for bottom-mounted installations.

The study of 10- to 20-meter long core samples should continue, but it is also urgent that scientists interested in naval problems study the long cores anticipated in the Joint Oceanographic Institutions Deep Earth Sample (JOIDES) program supported by the NSF. Down-hole measurements would also greatly advance understanding of sedimentary processes and the acoustical arts.

CRUSTAL AND SUBCRUSTAL STUDIES

The early measurements of the thickness and physical properties of the crust and shallow mantle in oceanic provinces were obtained in large part through Navy support. This field of investigation has considerably broader support today, but the Navy's interest continues because of the importance of these deeper acoustic paths. Very much more information is needed, requiring measurements with improved resolution, to obtain a more complete understanding of the ocean environment. The future studies should be made in many of the geographic areas not yet investigated; but more so, they should take advantage of the developing new instruments to make better measurements and the improvement of methods for analyzing

gravity fields, magnetic fields, heat-flow rates, acoustical propagation properties, and electrical conductivities of the crustal and subcrustal structures. Factors that affect the deflection of the vertical, for example, which have considerable application in geodesy and undersea warfare, include variations of sedimentary thickness, crustal thickness and densities, and upper-mantle depths and densities across such geologic features as oceanic trenches, sea mounts, and large escarpments.

Seismic reflection and refraction investigations should be extended to obtain information on crustal and subcrustal structures in areas of strategic significance that have been inadequately studied. These should be accompanied as consistently as possible by gravity, magnetic, and heat-flow measurements, and others, because their interpretation greatly strengthens the whole.

OCEANIC BIOLOGY

The quantity of definitive hydrobiological data is not at all uniformly distributed over the spectrum of Navy problem areas. We have amassed significant quantities of information, for example, on the important boring and fouling organisms at long-established operating depths with particular accent on piers and other fixed shore facilities. However, the entrance on the operational Navy scene of deep ocean submersibles will require and at the same time enable marine biologists to explore these great depths. The new deep submersibles have given the marine biologists the essential tools needed to begin an enlightened assault on the deep ocean aspects of such naval problems as toxic and obnoxious marine organisms, the ability of animals to orient and navigate in this abyssal environment, such unique behaviorial requisites for abyssal adaptation as bioluminescence, and the extreme physiological mechanisms which have been evolved by the deep ocean biota.

All the foregoing general areas of research are being actively investigated within the current hydrobiological program from the tide lines to moderate depths. In a continuing need for amplification, such areas as continental shelf ecology and

planktology will remain a major part of the Navy's biological research effort; in the deep ocean, these studies will constitute an expansion of this effort.

It is well known that the presence of marine organisms affect underwater acoustic detection by scattering or reflecting sound or by the masking of wanted signals by soniferous animals. It is not widely appreciated, however, that much of the knowledge of these effects is based upon very few observations in very limited geographic areas. In order to gain a fuller understanding of these effects, substantial expansion of programs on the acoustical characteristics of marine organisms is required.

UNDERWATER SOUND

The growing emphasis on more complex acoustic systems is expected to continue for some time. Modern systems depend heavily on sophisticated computer-oriented refinement of our understanding of the effects of the environment on such systems. Some specific areas are described in the following paragraphs.

Detailed knowledge of the energy-transfer process near large acoustic transmitters and receivers is required. For radiation at very high sound powers per unit area, water-compressibility effects become significant, and the transfer process becomes nonlinear. In some cases, equipments are so large that environmental conditions are not uniform over the entire area of the radiating face. The effects of these nonuniformities must be understood to insure maximum efficiency of systems.

Detection and communication systems of very large range are conceptually feasible. The cumulative effect of the ocean on sound transmission at long ranges must be determined in greater detail, and methods to predict performance in all of the ocean basins must be derived.

Effective achievement of the gain possible by using advanced signal-processing techniques requires much greater detail on signal structure, both desired signals and noise. For older systems, crude knowledge of frequency spectrum and amplitude sufficed, but in the future we must fully understand the total signal statistics and their environmental modifications.

As the requirements for the determination of size, shape, and speed of targets increase, acoustic systems of increased angular resolution, time resolution, and sensitivity will be needed. Since smaller segments of the ocean will be investigated in greater detail, scattering and reverberation phenomena must be known to higher precision. This implies more knowledge of scattering mechanisms at the ocean boundaries and at ocean structure discontinuities. The statistics of biological organism distribution must be improved, and methods of prediction of changes in this distribution made available.

Acoustics is considered as a hand tool of oceanography. Starting with the echo sounder and two abortive attempts at radio-acoustic ranging, acoustical systems have been employed in oceanography to measure distance underwater. Various systems now exist for submerged navigation that depend on measurement of acoustic travel times. The depths of tow nets and other oceanographic instruments are commonly telemetered acoustically or measured by means of an inverted echo sounder mounted on the instruments. The height of cameras above the sea floor is commonly measured by means of sound echoes. Underwater acoustic telephony has been an established means of communications for years. As design and reliability improve, all of these methods are coming into wider use, especially among oceanographers with no previous experience with acoustics. The trend is still developing and will probably be far more characteristic of the next ten to fifteen years in oceanography than over the past twenty. Although much experimentation is needed, and although several new concepts will be developed, the present requirement is for reliable, stable instruments.

SCIENTIFIC PLATFORMS AND INSTRUMENTATION

The task of conducting research on the oceans is a difficult one, and our present paucity of knowledge about this environment stems, in large measure, from the lack of adequate equipment in the past. The Navy's oceanographic shipbuilding pro-

gram, initiated in 1959, combined with that of the National Science Foundation, meets the needs of the oceanographic scientists both in Navy laboratories and private institutions with adequate ships of medium size. It appears that in the future, aside from presently planned construction, the need for additional ships will be for more large ones to handle the massive experimental equipment and auxiliary devices; and for additional smaller ones to meet specialized tasks. This latter category is particularly crucial from the viewpoint of the expenditures of research dollars for ship operation costs.

Major advances also have been made in recent years in the use of aircraft to obtain operational oceanographic information. With the development of air-droppable bathythermographs, the aircraft is becoming capable of providing information about subsurface layers as well as about the surface. Further developments of sensors and techniques for obtaining data from such platforms are underway. These developments are also a logical step toward the use of satellites to obtain oceanographic observations on a global basis. Satellite navigation systems already have made an impact on ocean-science research, and the use of satellites for telemetering oceanographic data from buoy systems is being evaluated. The Navy has been assigned the responsibility of determining the feasibility of deriving oceanographic measurements from space for the National Aeronautics and Space Administration. The results to date show promise for satellites as platforms from which to obtain information about the ocean environment.

Specialized and oftentimes complex instruments will be needed for the future ocean-science programs. Shipboard computers, underwater vehicles, long-range telemetering oceanographic buoys, improved echo sounders, and a host of new measurement tools will be required to gain a thorough understanding of oceans and their effects on naval operations. These equipments are expensive in comparison to past investments, but their potential payoff in terms of benefit to the Navy and to the Federal Government warrants the expenditure.

MAJOR COOPERATIVE EXPERIMENTS

The progress in the study of ocean circulation and internal waves, as well as the requirements for a general attack on the problems of air-sea interaction, have long made obvious the need for complex and extensive observational networks at sea. These, in turn, require advanced engineering design and development on a scale not previously pursued in scientific programs in physical oceanography. Preparations have been underway over the past few years for mounting major experimental networks in both the North Atlantic and the North Pacific. The large telemetering buoys previously discussed were developed in preparation for work on these and even larger scales of investigation. These plans require scientific resources beyond a single institution to supply, and they also require a major effort in formulation and execution. Suitable combinations of research groups are now working on program studies, and it is anticipated that the next few years will see major efforts in the Navy Ocean Science Program. It seems clear that this effort can be useful to other programs of the Federal Government in furthering its national and international objectives. Co-operative planning with other federal agencies to this end has already begun.

OCEAN EXPLORATION AND EXPLOITATION

Today we can predict man's access to the ocean depths as freely as our forebears predicted access to the surface areas of the world. We, as they, must bend our efforts to make this access as safe and economic as possible. To this end, future efforts must continue to expand our knowledge of basic materials, structures, propulsion, and communications to provide a continuing evolution of techniques.

Since the missions and tasks of ocean exploration and exploitation will be many and varied, no single system or technique will suffice. Manned systems, represented by saturation diving and small submersibles, are expected to be the most

flexible and useful for the next few years. They will be supplemented by deep-towed semiautomatic sensory and work-performing systems. As task areas become better defined, we can expect full computer-commanded automation to perform a greater percentage of the work functions. This implies a broad spectrum of research—both in the basic problems specific to the oceans and the integration of techniques from other areas of science (computer, *etc.*) to the ocean environment.

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In order to insure timely progress in the programs discussed in this report, and generally to respond to those needs of the Navy, the Federal Government, and the Nation that can properly be met by naval ocean science, a number of concerns and responsibilities must be addressed. The Navy must be aware of its immediate technical needs in this area and of the probable requirements to be faced for many years to come. To this end, it will be necessary to develop resources in manpower, facilities, ships, and budgetary support. This development requires long-term planning of research programs, the identification and development of talent for a wide variety of responsibilities, and repeated review of scientific and technological progress within the program and on the national and international scenes.

A prime responsibility is suitable and timely interaction with other technical and operational groups within the Navy to ensure their awareness of the influence of the oceanic environment on their programs.

The encouragement of interaction with other ocean-science communities is important. Cooperative research projects should be conducted, and new findings should be critically examined. This activity should be extended beyond oceanography in its broadest definition to ensure that oceanography benefits from scientific and technological progress in general. The Navy must also play its proper role by furnishing to the Federal Government and to the public at large such information about this program

as may be released in the national interest. In the past the naval ocean science community has responded to a very broad spectrum of special needs on an emergency basis. Similar emergencies will doubtless arise in the future. This is by no means a complete catalog, but serves to suggest the pattern of responsibility to be addressed.

In view of these responsibilities, and after the period of experimentation described in the Introduction to this report, a recent decision has been reached to establish the Maury Center of Ocean Science, discussed previously. It is intended to function as a focus of concern about the broad problems of the ocean-science program; it will also serve as a research activity directly responsible for parts of the total program.